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# **Lifetime and Spectroscopy of Bottom and Charm Hadrons**

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### Introduction

Physics motivation

### Spectroscopy

- Charm hadrons
- Bottom hadrons

### Lifetime

- Charm hadron lifetimes
- Bottom hadron lifetimes

I discuss mainly bottom hadrons.

## Why spectroscopy and lifetime?

Mass and lifetime are the fundamental properties of a particle.

→ Entries to Particle Data Book.

**For bottom and charm hadrons:**

### Spectroscopy

- Insights into QCD potential.
- All pseudoscalar and vector states have been established.
- Some  $L = 1$  states established, others just coming out.
- Heavy quark symmetry.

N. Isgur and M. Wise, Phys. Rev. Lett. **66**, 1130 (1991).

J. Rosner, Comm. Nucl. Part. Phys. **16**, 109 (1986).

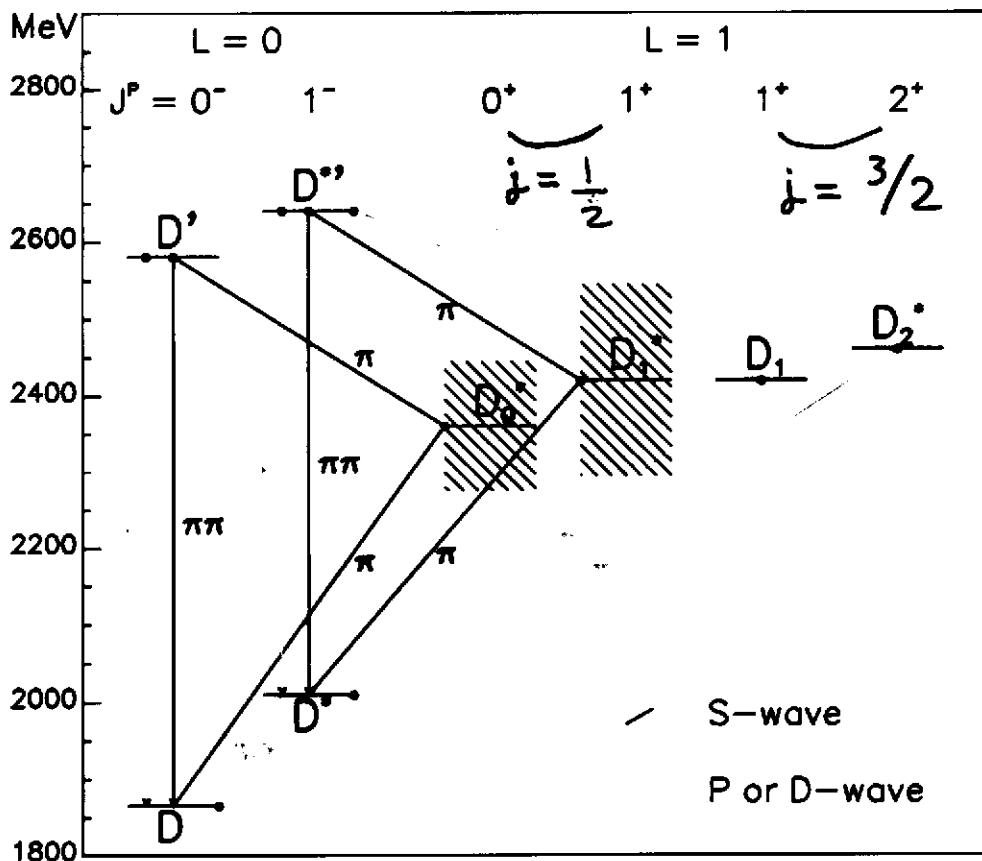
Heavy-light meson is more like the hydrogen atom rather than the positronium.

## Lifetime

- Need  $\tau = 1/\Gamma$  to extract  $|V_{cb}|$ ,  $|V_{cs}|$ .
- At zero-th order, the decay of a heavy hadron is the decay of a heavy quark  $Q$ .  
→ All hadrons with  $Q$  should have the same lifetime.
- For charm, this is far from reality:  
$$\tau(D^+) \sim 2.5 \times \tau(D^0).$$
Perhaps charm is not heavy enough.  
Should be a better approximation for bottom.
- Heavy quark expansion to predict lifetime differences.  
$$\Delta\tau \sim \mathcal{O}(10\%)$$
 for  $B$  hadrons.
- Experimental precision still getting better.  
 $D_s^+$  lifetime is different from  $D^0$ .  
Beginning to see  $\tau(B^+) > \tau(B^0)$ ?  
 $\Delta\Gamma \neq 0$  in  $B_s^0$ - $\overline{B}_s^0$  system?

# Charm Spectroscopy

## Spectroscopy of D mesons



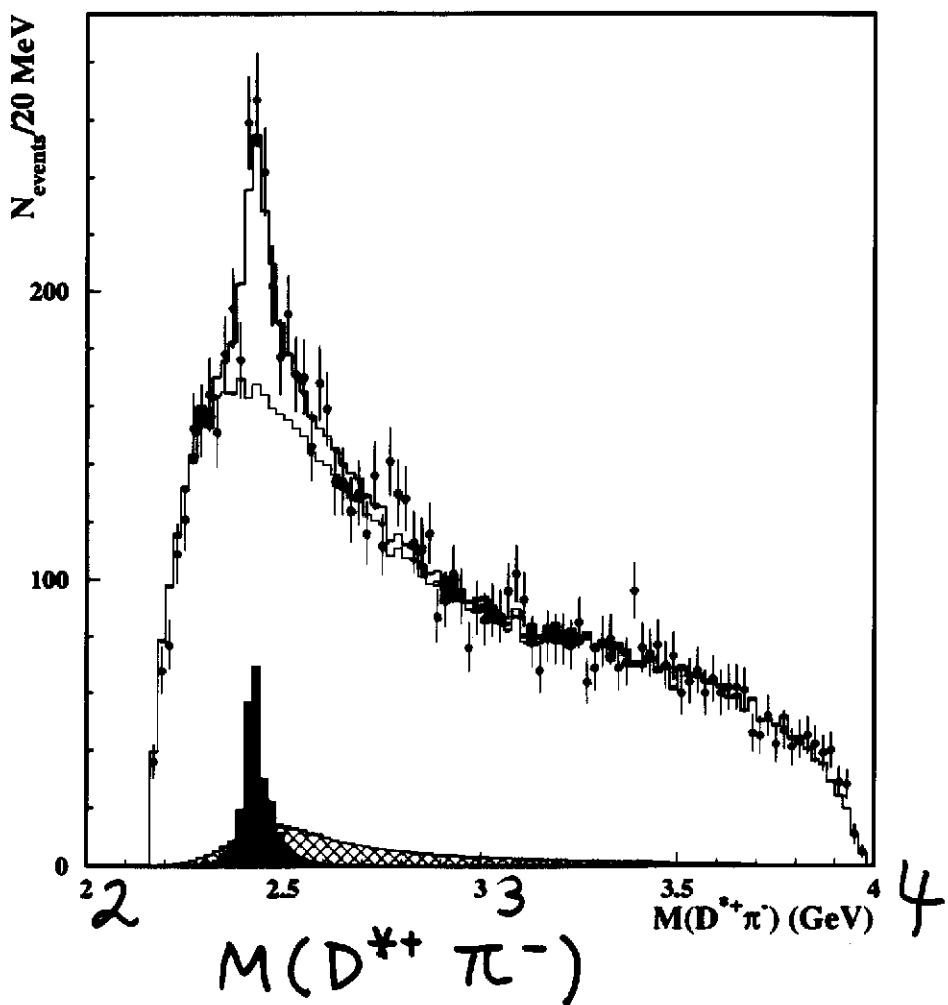
- $D^{**}$  mesons:  $c\bar{q}$  states with  $L = 1$ .
- $L = 1$  and  $S = 0, 1 \rightarrow$  Four states,  $J^P = 1^+, 0^+, 1^+, 2^+$ .
  - $J^P = 0^+$  to  $D\pi$ ,  $J^P = 1^+$  to  $D^*\pi$ ,  $J^P = 2^+$  to  $D\pi$ ,  $D^*\pi$ .
- HQET: (in the limit of  $m_Q = \infty$ )
  - For a  $Q\bar{q}$  system,  $j = L + S_{\bar{q}}$  is a good quantum number.
  - doublets with  $j = 1/2$  ( $J = 0, 1$ ) and  $j = 3/2$  ( $J = 1, 2$ ).
  - $j = 3/2$  doublet decays via only  $D$ -wave  $\Rightarrow$  Narrow.
  - $j = 1/2$  doublet decays via only  $S$ -wave  $\Rightarrow$  Broad.
  - $D_1$  and  $D_2^*$  (narrow) states have been established.

## Wide $D^{**}$ States

CLEO: CLEO CONF 99-6

Use  $B^- \rightarrow D^{*+}\pi^-\pi^-$ , and study  $D^{*+}\pi^-$  pairs.

Partial reconstruction:  $D^{*+} \rightarrow D^0\pi^+$  but  $D^0$  not reconstructed.



$$m = 2461^{+41}_{-34} \pm 10 \pm 32 \text{ MeV}/c^2.$$

$$\Gamma = 290^{+101}_{-79} \pm 26 \pm 36 \text{ MeV}/c^2.$$

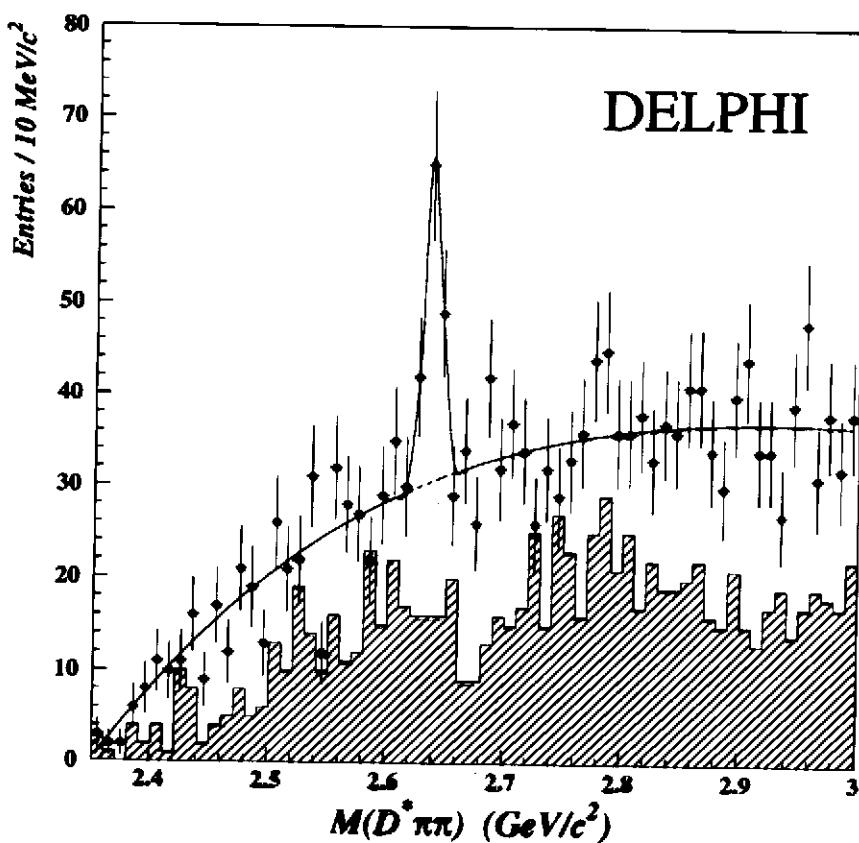
$$\begin{aligned} & \mathcal{B}(B^- \rightarrow D_1^{*0}\pi^-) \cdot \mathcal{B}(D_1^{*0} \rightarrow D^{*+}\pi^-) \\ &= (10.6 \pm 1.9 \pm 1.7 \pm 2.3) \times 10^{-4}. \end{aligned}$$

## Radial Excitation $D^{* \prime}$

**DELPHI:** Phys. Lett. **B426**, 231 (1998).

$$D^{* \prime +} \rightarrow D^{*+} \pi^+ \pi^- ,$$

$$\text{with } D^{*+} \rightarrow D^0 \pi^+, D^0 \rightarrow K^- \pi^+, K^- \pi^+ \pi^+.$$



Signal:  $66 \pm 14$  events.

$$m(D^{* \prime}) = 2637 \pm 2 \pm 6 \text{ MeV}, \Gamma < 15 \text{ MeV at 95\% C.L.}$$

Not seen by OPAL or CLEO.

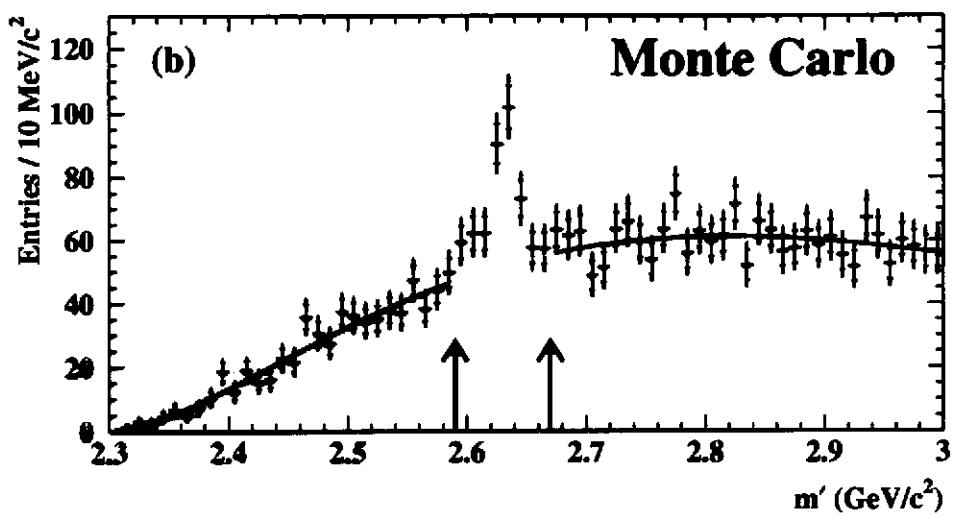
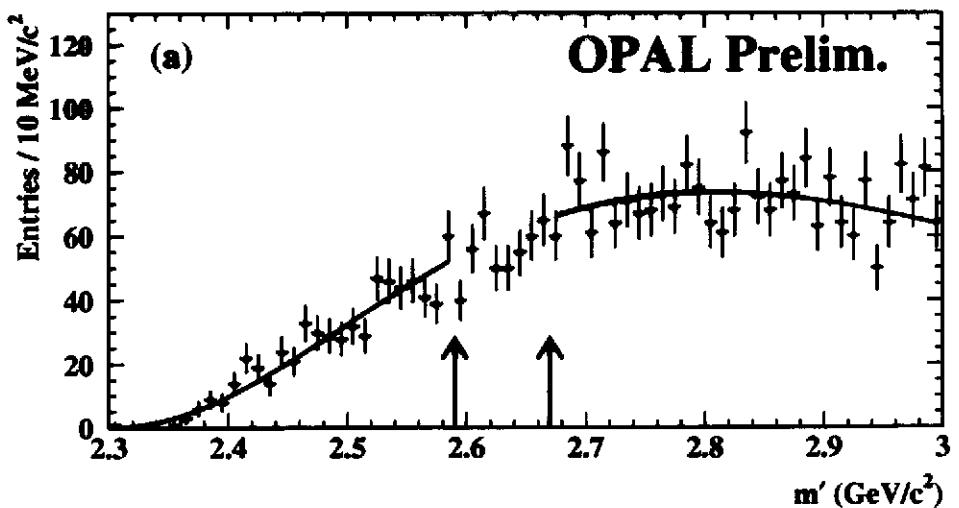
Ratio  $R = N(D^{* \prime} \rightarrow D^{*+} \pi^+ \pi^-) / N(D_1^0, D_2^{*2} \rightarrow D^{*+} \pi^-)$ :

$$R = 0.49 \pm 0.18 \pm 0.10 \text{ DELPHI}$$

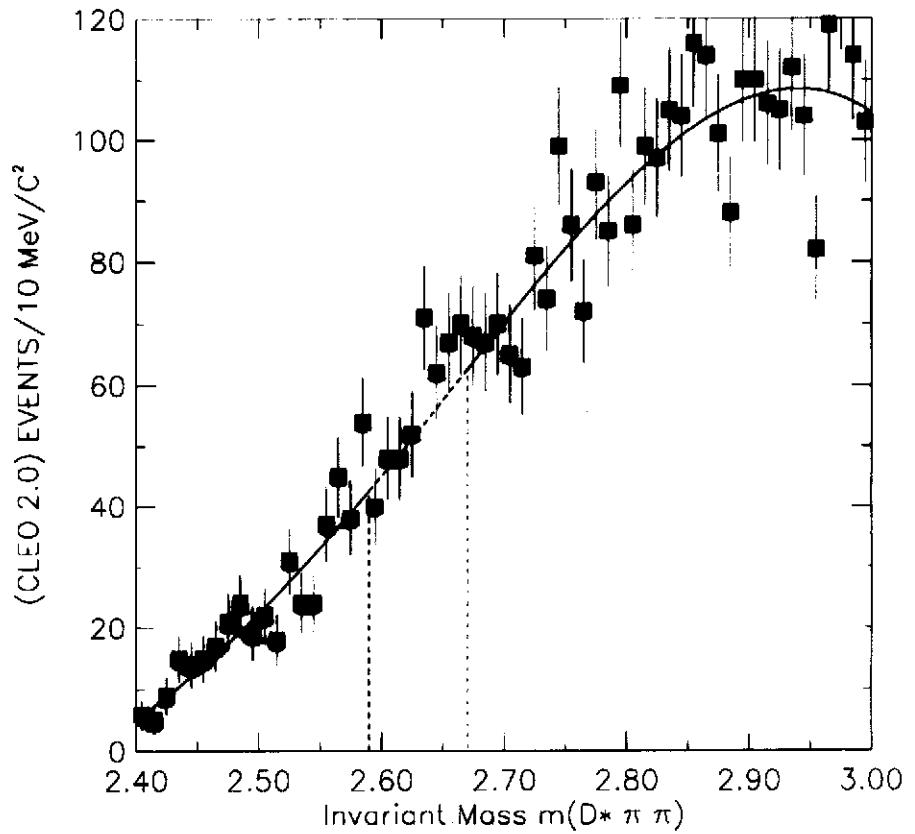
$$R < 0.21 \text{ (95\% C.L.) OPAL PN 352 (ICHEP98)}$$

$$R < 0.16 \text{ (90\% C.L.) CLEO hep-ex/9901008}$$

**OPAL**  
PN 352  
(ICHEP 98).



**CLEO**  
hep-ex/9901008.



## Charmed Baryons

**CLEO:** Phys. Rev. Lett. **83**, 3390 (1999).

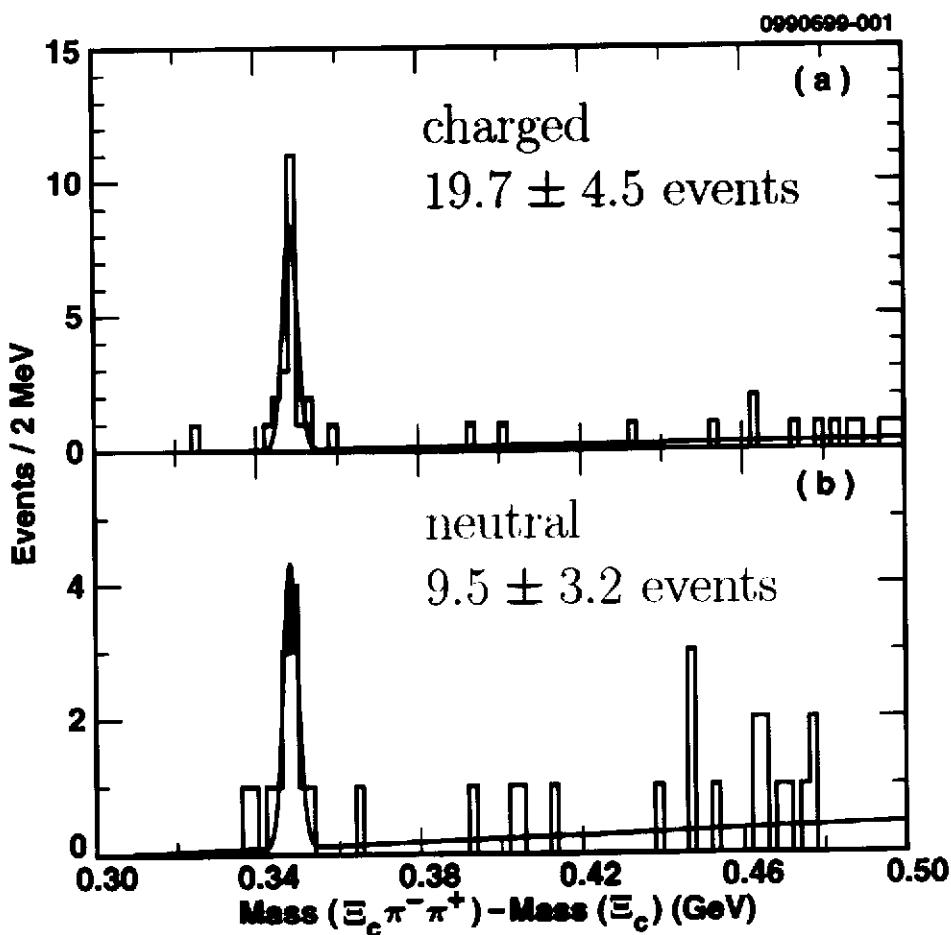
4.8  $\text{fb}^{-1}$  of  $e^+e^-$  annihilation near  $\Upsilon(4S)$ .

Charged  $\rightarrow \Xi_c^+\pi^+\pi^-$  via  $\Xi_c^{*0}\pi^+$ .

Neutral  $\rightarrow \Xi_c^0\pi^+\pi^-$  via  $\Xi_c^{*+}\pi^-$ .

$\Xi_c^+$  ( $\Xi_c^0$ ) reconstructed in 3 (6) modes, e.g.  $\Xi^0\pi^+\pi^-$  ( $\Xi^-\pi^+$ ).

Examine the mass difference  $\Delta m \equiv m(\Xi_c^*\pi) - m(\Xi_c^*)$ :



Mass:  $\Delta m = 348.6 \pm 0.6$  and  $347.2 \pm 0.7$  MeV.

Width:  $\Gamma < 3.5$  and  $< 6.5$  MeV.

Interpreted as the  $J^P = \frac{3}{2}^-$   $\Xi_{c1}$  isospin doublet.  
 ( $L = 1$  orbital excitation of  $\Xi_c$ )

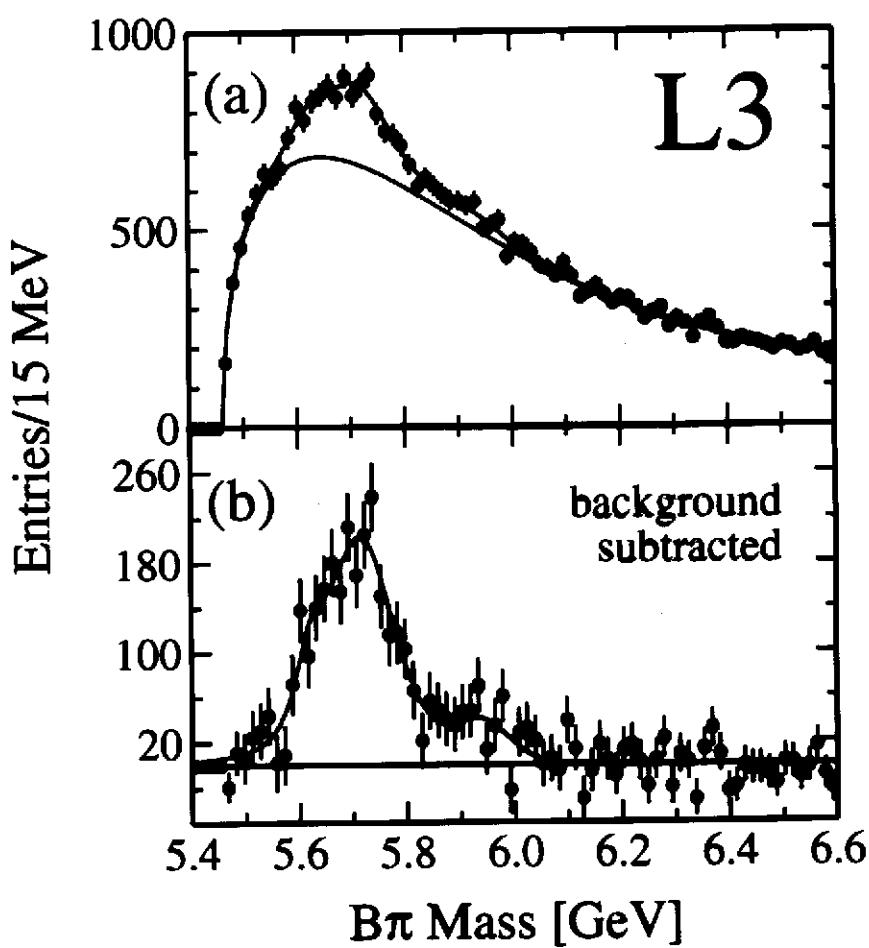
## Bottom Spectroscopy

- $B$  and  $B^*$  well established.
- $B^{**}$  seen (LEP, CDF).

**L3:** L3 Note 2423 (EPS 99)

Inclusive  $B$  reconstruction (secondary vertex).

Combine with a pion from the primary vertex  $\rightarrow m(B\pi)$ :



FIT:

$M_{B_2^*}, M_{B_1^*}$  : free

$M_{B_2^*} - M_{B_1} = 12 \text{ MeV}$

$M_{B_1^*} - M_{B_0^*} = 12 \text{ MeV}$

Widths: free, but  
common within  
a doublet

Also, fifth,  
component for  
 $B'$

$B_1^*$ :  $m = 5670 \pm 10 \pm 13 \text{ MeV}$ ,  $\Gamma = 70 \pm 21 \pm 25 \text{ MeV}$ .

$B_2^*$ :  $m = 5768 \pm 5 \pm 6 \text{ MeV}$ ,  $\Gamma = 24 \pm 19 \pm 24 \text{ MeV}$ .

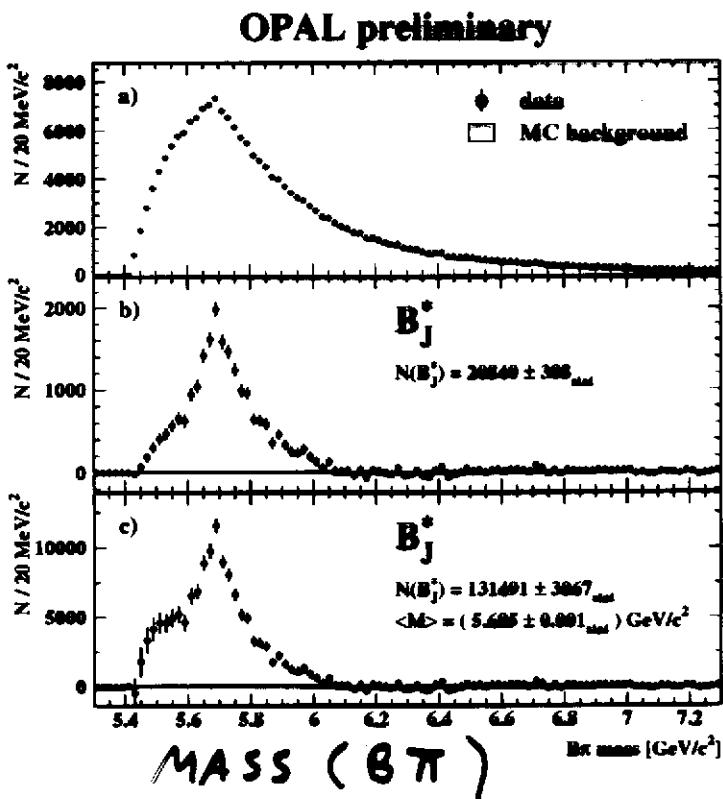
$f(b \rightarrow B^{**} \rightarrow B^{(*)}\pi) = 0.32 \pm 0.03 \pm 0.06$ .

Also  $B'$ :  $m = 5937 \pm 21 \pm 4 \text{ MeV}$ ,  $\sigma = 50 \pm 22 \pm 5 \text{ MeV}$ .

$f(b \rightarrow B' \rightarrow B^{(*)}\pi) = 0.034 \pm 0.011 \pm 0.008$ .

# OPAL: OPAL note PN400 (EPS 99)

Inclusive  $B$  reconstruction + pion  $\rightarrow m(B\pi)$ :



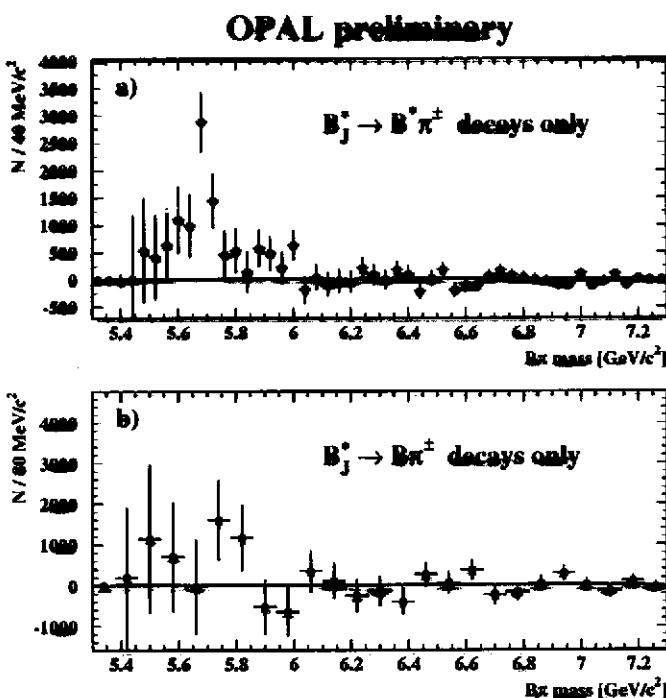
Raw

BG sub.

Eff. corr.

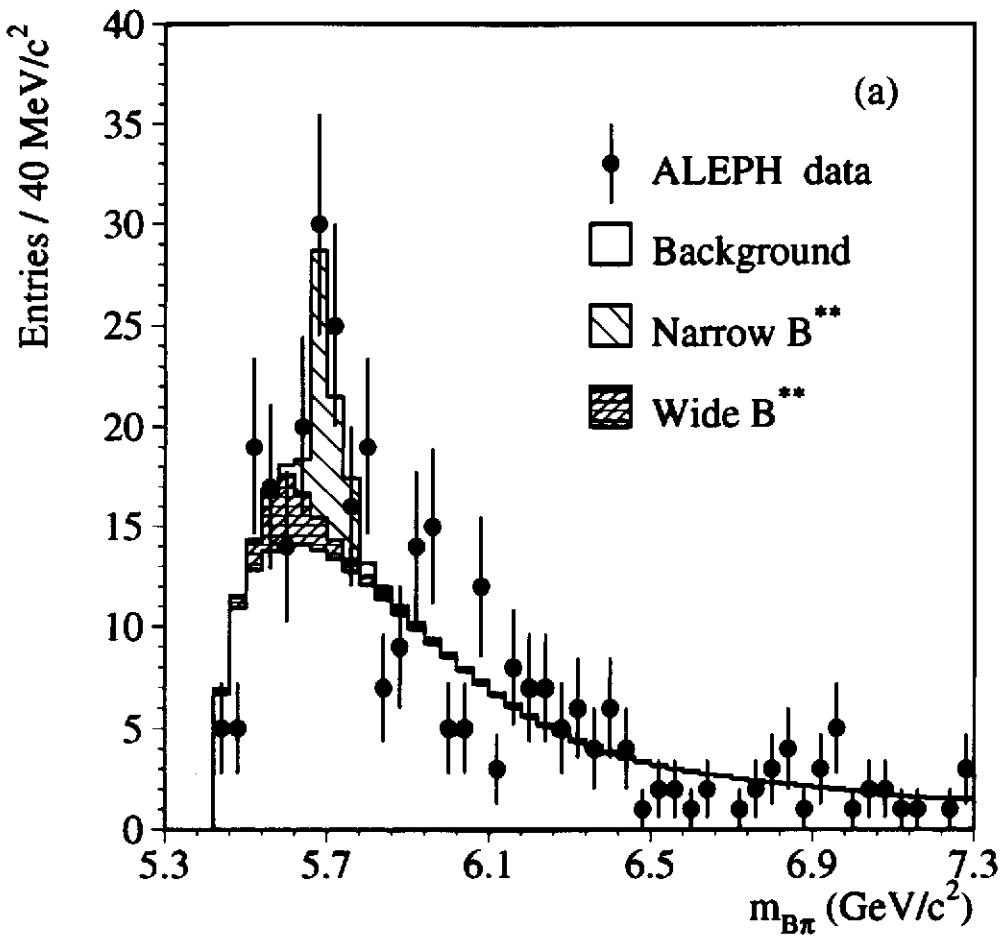
Statistical separation of  $B^{**} \rightarrow B\pi$  and  $B^{**} \rightarrow B^*\pi$  by looking at  $\gamma$  from  $B^*$ .  $\Rightarrow B^*$ -enriched and  $B^*$ -depleted samples.

$$\mathcal{B}(B^{**} \rightarrow B^*\pi) = 0.85^{+0.26}_{-0.27} \pm 0.12.$$



**ALEPH**: Phys. Lett. **B425**, 215 (1998).

Use fully reconstructed decays  $B \rightarrow D^{(*)} n\pi$ ,  $J/\psi K^{(*)}$ ,  
to get better resolution in  $m(B)$  and thus in  $m(B\pi)$ :



$$\left. \begin{array}{l} m(B_2^*) = 5739_{-11}^{+8} {}_{-4}^{+6} \text{ MeV.} \\ f(b \rightarrow B^{**} \rightarrow B^{(*)}\pi) = 0.31 \pm 0.09_{-5}^{+6}. \end{array} \right\}$$

FROM A FIT ASSUMING HQS PREDICTIONS

$$\Gamma(B_2^*) = 25 \text{ MeV}$$

$$M(B_1) = M(B_2^*) - 12 \text{ MeV}, \quad \Gamma = 21 \text{ MeV}$$

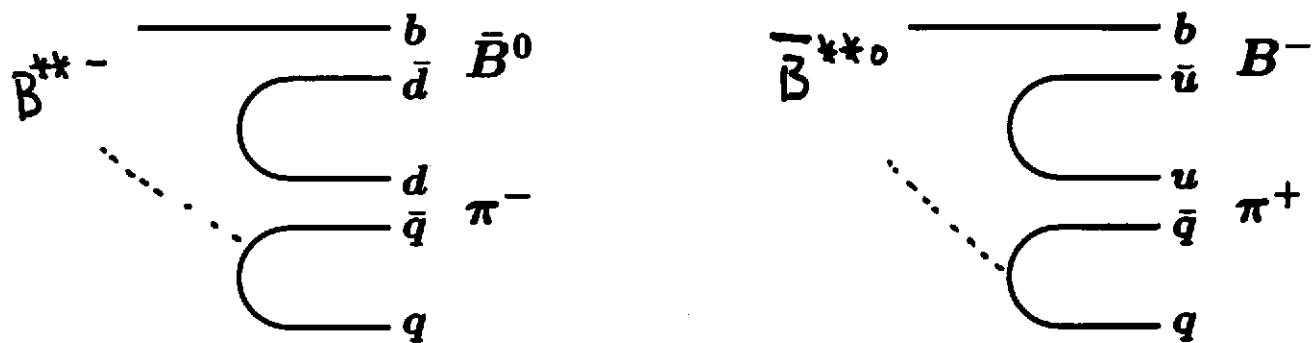
$$M(B_1^*) = M(B_2^*) - 100 \text{ MeV}, \quad \Gamma = 150$$

$$M(B_0) = M(B_1^*) - 12 \text{ MeV}, \quad \Gamma = 150$$

RELATIVE RATES :  $2J+1$  SPIN COUNTING

- $B^{**}$  important for “same-side” flavor tagging :

- Example:  $D^{*+} \rightarrow D^0 \pi^+$ .
- $m(B^*) - m(B) \sim 50 \text{ MeV}/c^2$ , then  $B^* \rightarrow B\gamma$ .
- $B^{**}$  is the main state that can give a correlated charged particle.
- Also fragmentation particles contribute.



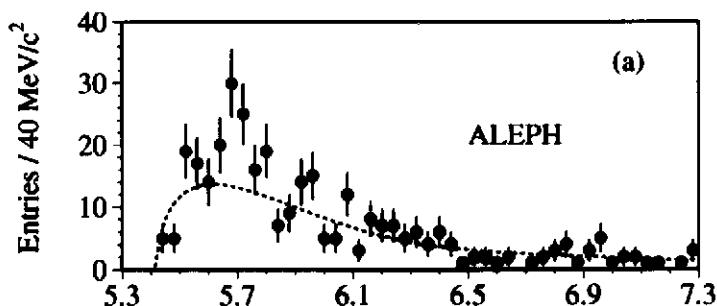
Charge correlation is the same regardless of resonant ( $B^{**}$ ) or non-resonant (fragmentation).

Need to separate charged and neutral  $B$ 's.

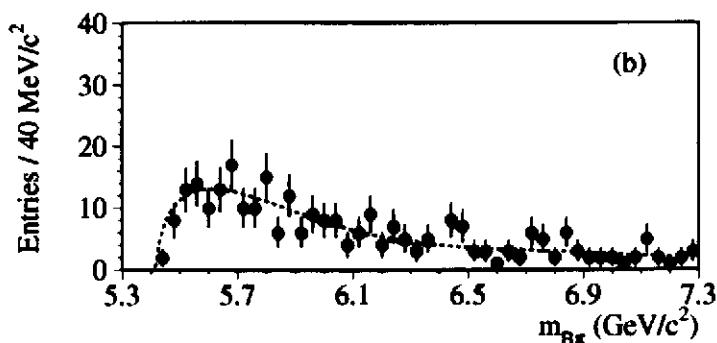
## ALEPH: $B^{**}$ analysis (continued).

Fully reconstructed decays,  $B \rightarrow D^{(*)} n\pi$ ,  $J/\psi K^{(*)}$ ,  
and look at “right-sign” and “wrong-sign” pions :  
(actually previous plot was already for right-sign)

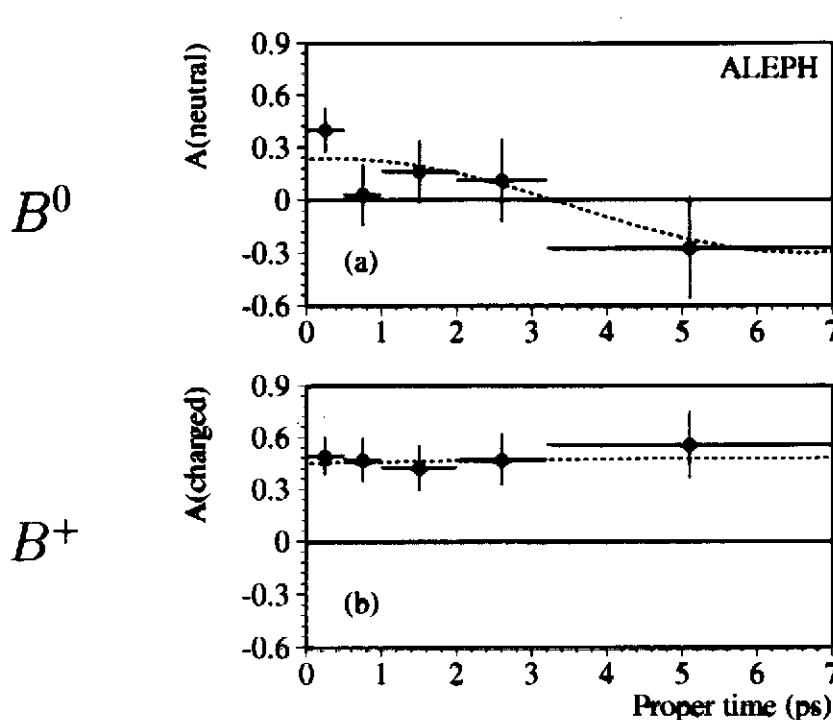
Right sign



Wrong sign



Time development of asymmetry.  $\Rightarrow$  mixing for  $B^0$  !



*TAG PURITY*  
“DILUTION” =  $1 - 2W$

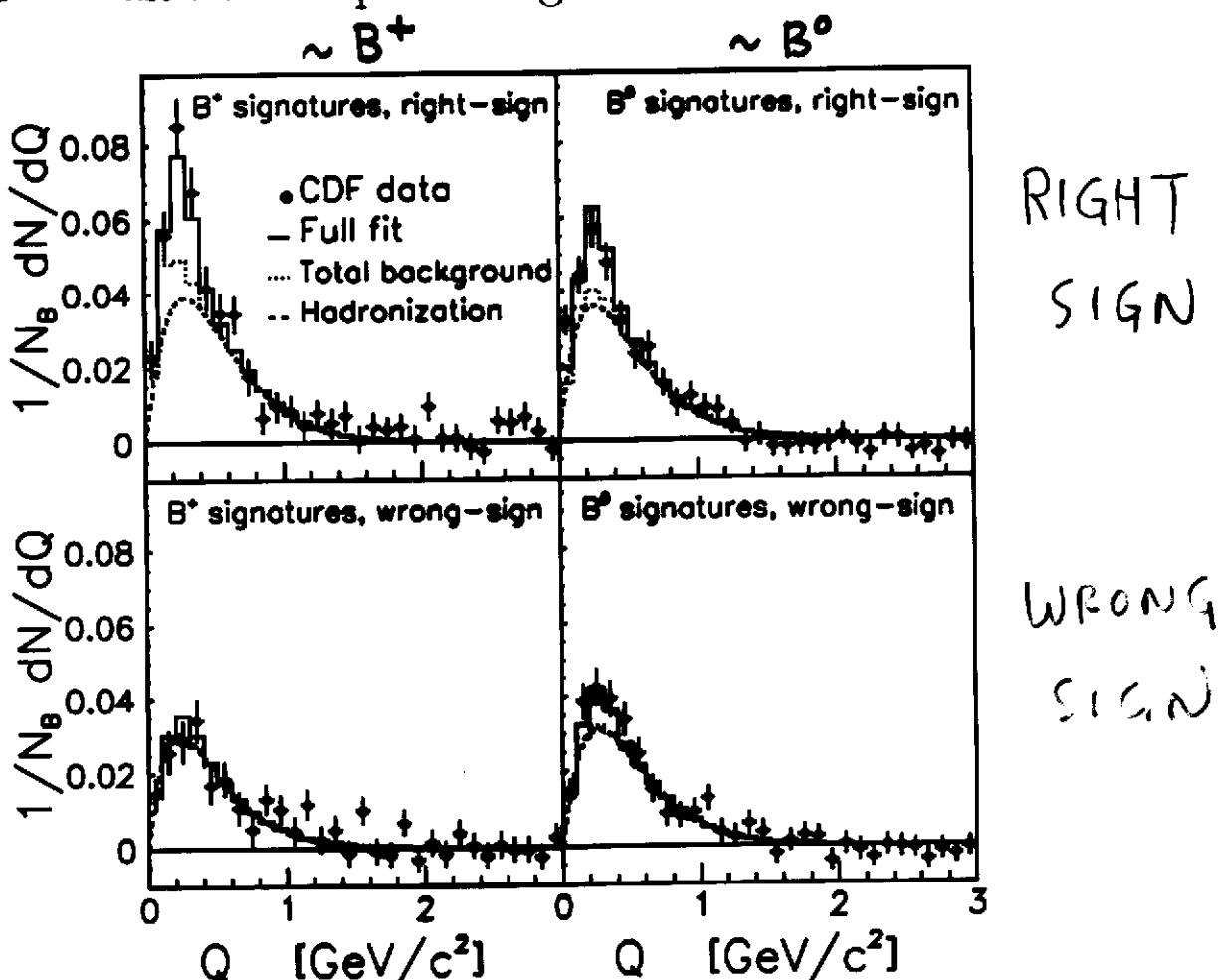
$$D = 0.31 \pm 0.11$$

*WRONG TAG PROB.*

$$D = 0.48 \pm 0.07$$

**CDF:** FERMILAB-Pub-99/330-E, submitted to PRD.

Use  $\ell^- D^{(*)+}$  and  $\ell^- D^0$  pairs to get  $\bar{B}^0$  and  $B^-$ .



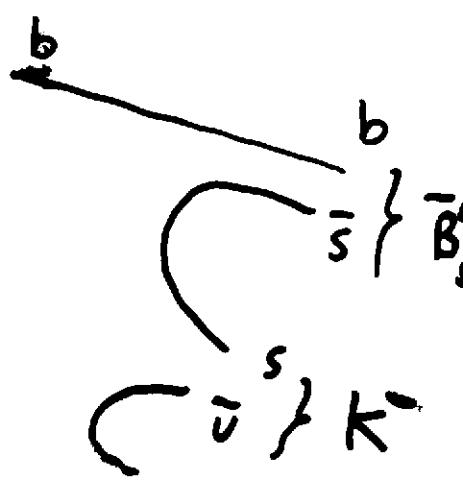
Note:

Tag purity (dilution) higher for  $B^+$  than for  $B^0$ :

The  $s$ -quark in the second fragmentation chain helps  $B^+$ , hurts  $B^0$ .

Particle ID should help, esp. for  $B_s^0$ .

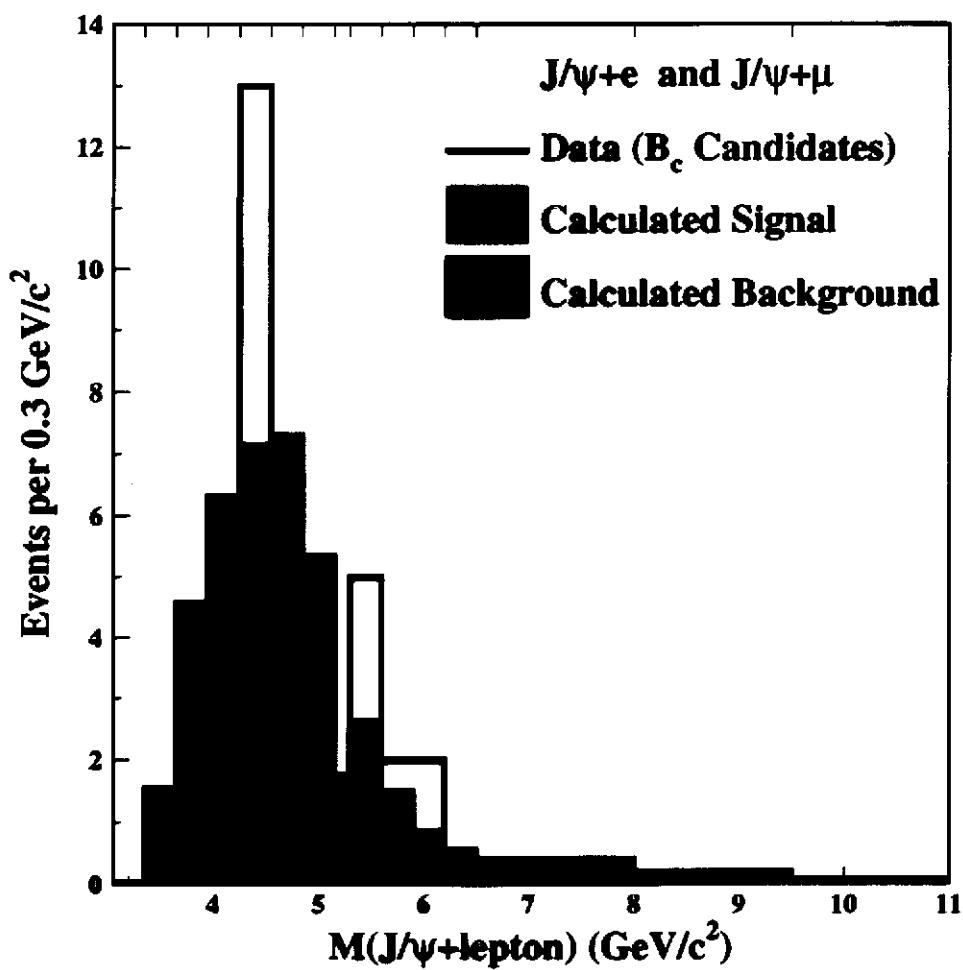
Could get higher purity when cut on mass.



## The $B_c^\pm$ meson

$B_c^- \equiv b\bar{c}$ , contains two different heavy quarks.

**CDF:** PRL **81**, 2432 (1998); PRD **58**, 112004 (1998).  
Use semileptonic decay  $B_c^- \rightarrow \ell^- \bar{\nu} J/\psi X$ ,  $J/\psi \rightarrow \mu^+ \mu^-$ .  
Look at the three lepton mass:



Signal:  $N(B_c) = 20.4^{+6.2}_{-5.5}$ .

$M(B_c) = 6.40 \pm 0.39 \pm 0.13 \text{ GeV}/c^2$ .

Should see exclusive decays e.g.  $B_c^- \rightarrow J/\psi \pi^-$  in Run II.

## Charm hadron lifetimes

Lifetimes are different among charm hadrons:

- $\tau(D^+)/\tau(D^0) \simeq 2.5$   
 $\tau(D_s^+)/\tau(D^0) \sim 1$   
 $\tau(\Lambda_c^+)/\tau(D^0) \sim 0.5$
- Final-state Pauli interference, annihilation and  $W$ -exchange processes must be very important.

Recent developments:

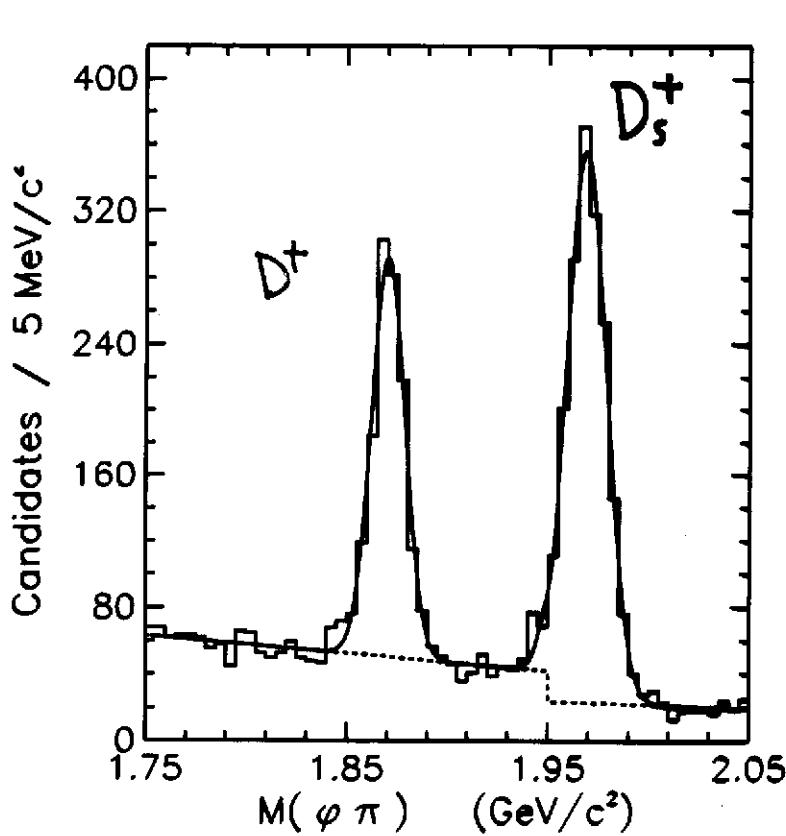
- New precision in  $D_s^+$  lifetime  
E791, CLEO.  
Now  $\tau(D_s^+) \neq \tau(D^0)$  established.
- New experiments: FOCUS, SELEX

**E791:** Phys. Lett. **B445**, 449 (1999).

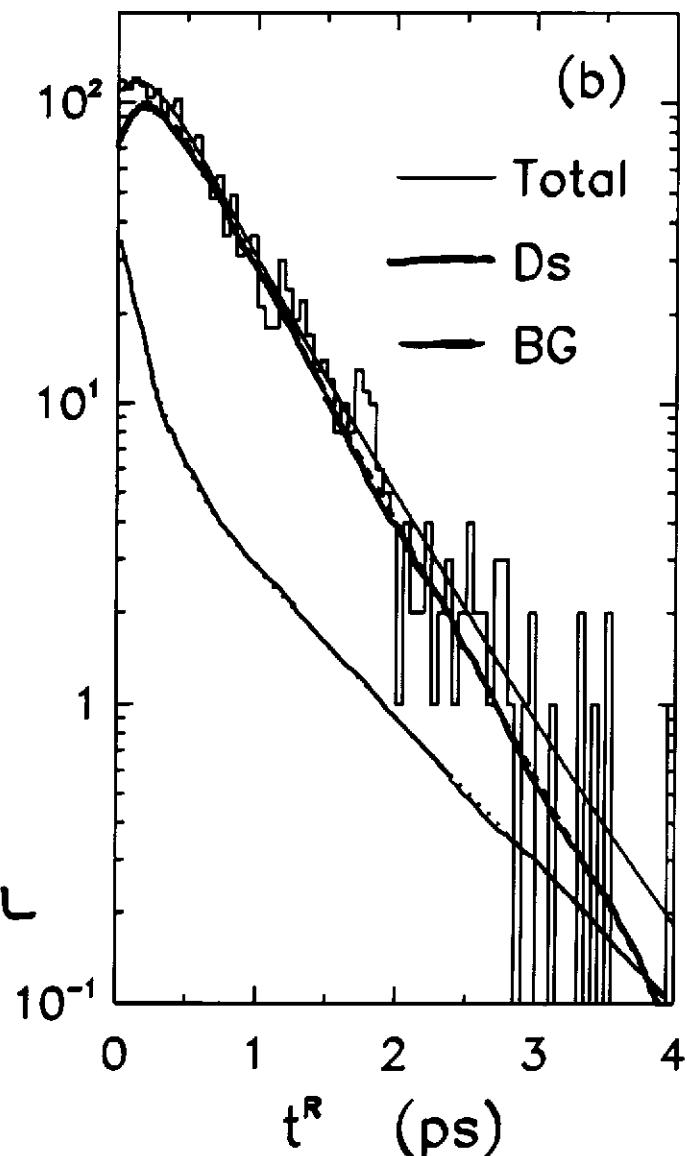
500 GeV  $\pi^-$  beam on foil targets. Data in 1991 - 92.

$D_s^+ \rightarrow \phi\pi^+$ ,  $\phi \rightarrow K^+K^-$ .

Fit mass and decay time distributions simultaneously.



$D_s^+ : 1662 \pm 56$  SIGNAL



$$\tau(D_s^+) = 518 \pm 14 \pm 7 \text{ fs}$$

$$\tau(D_s^+)/\tau(D^0) = 1.25 \pm 0.04 \text{ using } \tau(D^0) = 415 \pm 4 \text{ fs (PDG 98).}$$

$$D^+ : 997 \pm 39$$

$$\text{check: } \tau(D^+) = 1065 \pm 48 \text{ fs}$$

**CLEO**: Phys. Rev. Lett. **82**, 4586 (1999).

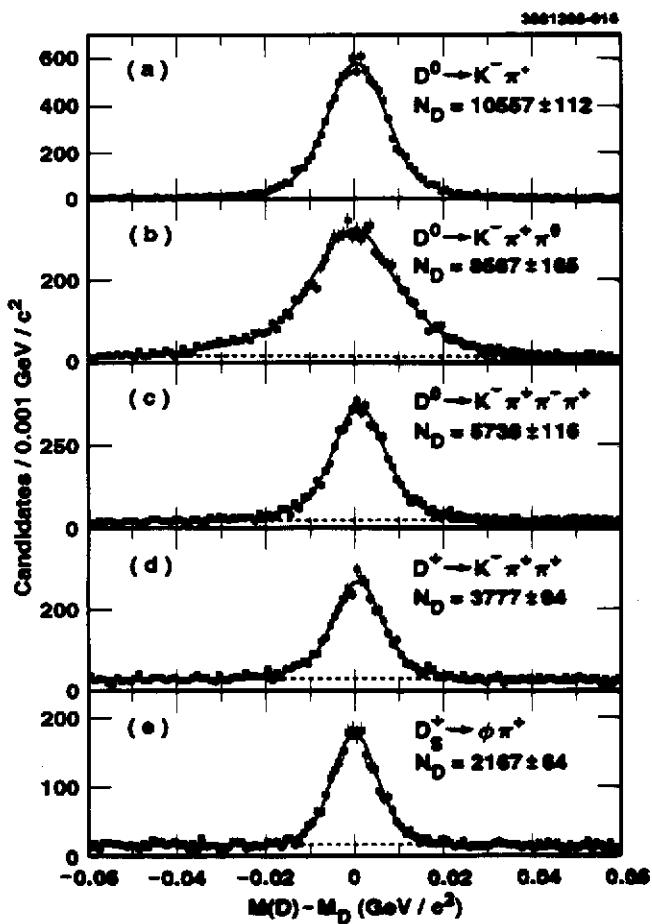
3.7  $\text{fb}^{-1}$  of  $e^+e^-$  annihilation near  $\Upsilon(4S)$ .

$D$  states reconstructed with:

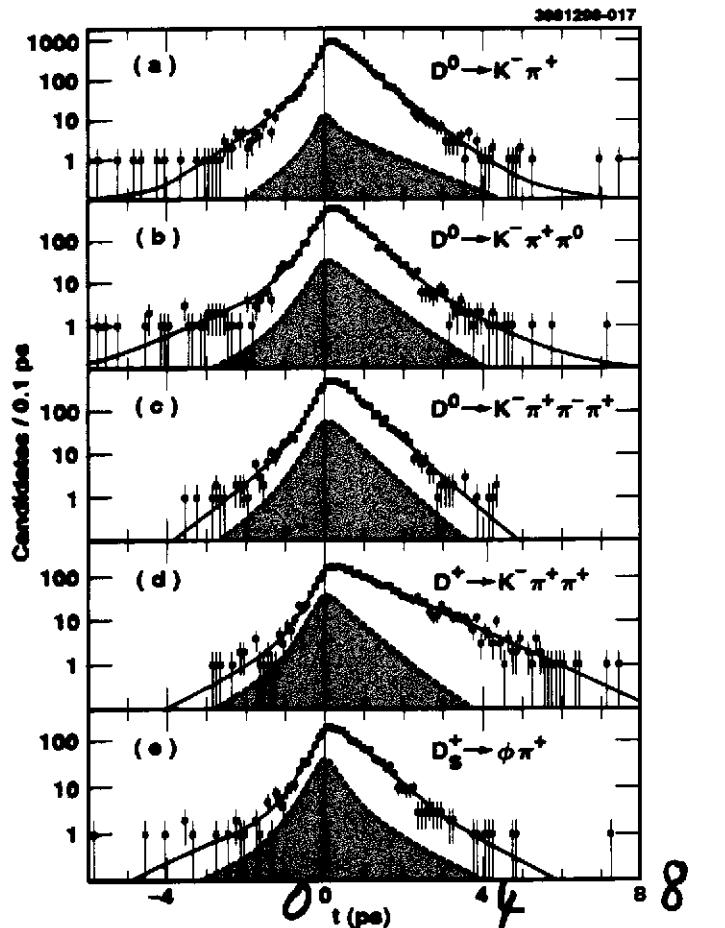
$$\left. \begin{array}{l} D^0 \rightarrow K^-\pi^+, K^-\pi^+\pi^0, K^-\pi^+\pi^+\pi^- \\ D^+ \rightarrow K^-\pi^+\pi^+ \\ D_s^+ \rightarrow \phi\pi^+, \phi \rightarrow K^+K^- \end{array} \right\}$$

Use  
 $D^{\star+} \rightarrow D^0\pi^+$   
 $D^+\pi_0$   
 to get high purity.

$D$  decay vertex from silicon vertex detector.  
 Beam spot as the primary vertex.



$M_{\text{REC}} - M_D$  (GeV)



DECAY TIME (ps)

$$\tau(D^0) = 408.5 \pm 4.1 \pm 3.5 \text{ fs}$$

$$\tau(D^+) = 1033.6 \pm 22.1 \pm 9.9 \text{ fs}$$

$$\tau(D_s^+) = 486.3 \pm 15.0 \pm 4.9 \text{ fs}$$

$$\tau(D_s^+)/\tau(D^0) = 1.19 \pm 0.04$$

## Bottom hadron lifetimes

### Predictions:

- $\sim 10\%$  difference between  $B^+$  and  $B^0$ .
- $\sim 1\%$  between  $B_s^0$  and  $B^0$ .
- $\sim 0.9$  for baryons/ $B^0$ .

### Techniques:

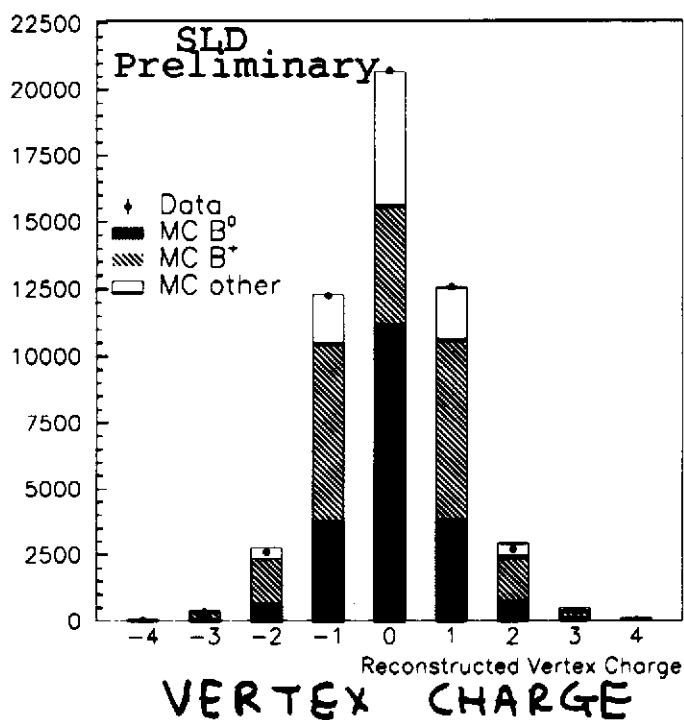
- Inclusive reconstruction
  - Inclusive secondary vertex reconstruction.
  - Vertex charge to separate charged and neutral.
  - Largest statistics, but samples less pure.
- Partial reconstruction (e.g. semileptonics)
  - Lepton with fully reconstructed charm meson.
  - Statistics respectable.
  - $D^{**}$  introduces  $B^+/B^0$  admixture. PURITY  $\approx (80-90)\%$
- Full reconstruction
  - $B$  mass peak in e.g.  $J/\psi K^{(*)}$  or  $D^{(*)}n\pi$ .
  - 100% purity.
  - Momentum known precisely for each event.
  - Don't have to assume anything. Free from systematics.
  - Low stat due to branching fractions.

**SLD:** SLAC-PUB-8206 (EPS99, LP99)

350 k hadronic  $Z^0$  decays (97 - 98).

Inclusive  $B$  reconstruction (secondary vertex).

Vertex charge:

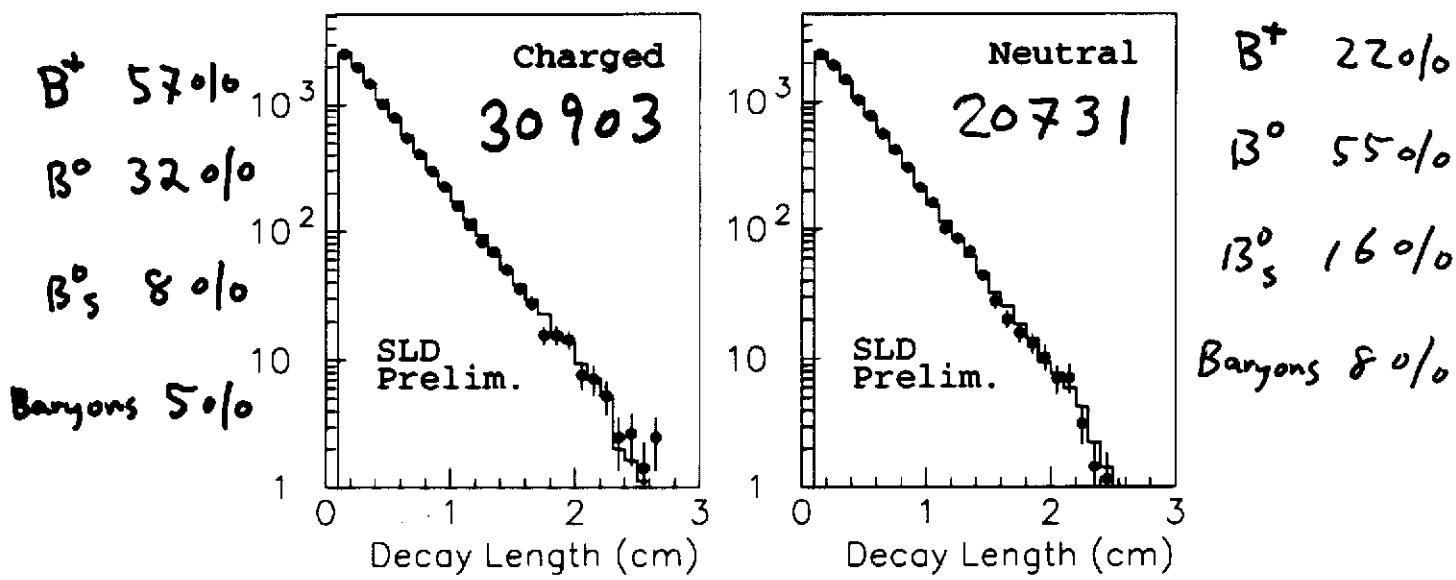


CHARGED

$$\equiv Q = \pm 1, \pm 2, \pm 3.$$

NEUTRAL

$$\equiv Q = 0$$



$$\tau(B^+) = 1.623 \pm 0.020 \pm 0.034 \text{ ps}$$

$$\tau(B^0) = 1.589 \pm 0.021 \pm 0.043 \text{ ps}$$

$$\tau(B^+)/\tau(B^0) = 1.037^{+0.025}_{-0.024} \pm 0.024$$

ENHANCE PURITY FURTHER w/ VERTEX MASS, POLARIZATION,

# ALEPH: ALEPH 99-005 (winter 99)

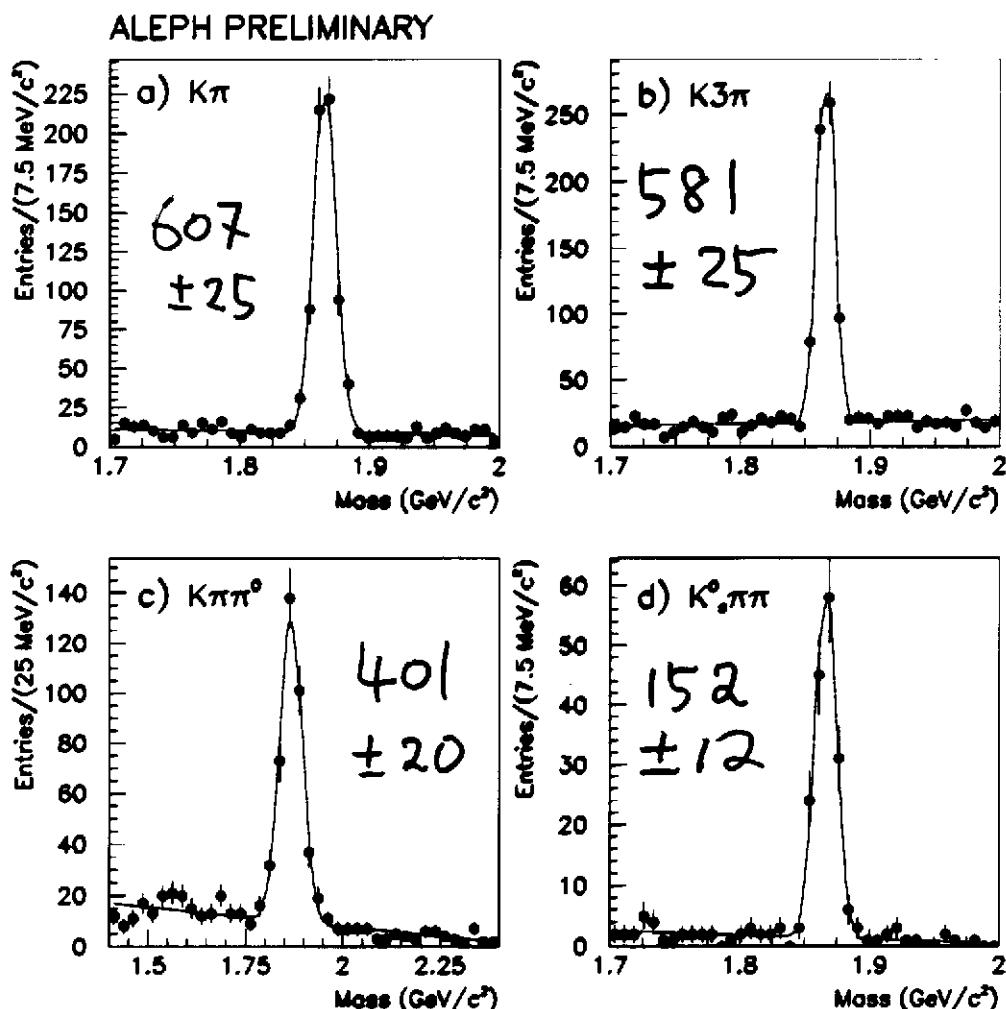
Re-analysis of 4 M hadronic  $Z^0$  decays (91 - 95).

Use  $\ell^- D^{*+}$  (mostly  $\bar{B}^0$ ) and  $\ell^- D^0$  (mostly  $B^-$ ) events.

Charm reconstruction:

$$D^{*+} \rightarrow D^0 \pi^+,$$

with  $D^0 \rightarrow K^- \pi^+$ ,  $K^- \pi^+ \pi^+ \pi^-$ ,  $K^- \pi^+ \pi^0$ ,  $K_S^0 \pi^+ \pi^-$ .



$D^0$  not from  $D^{*+}$ ,

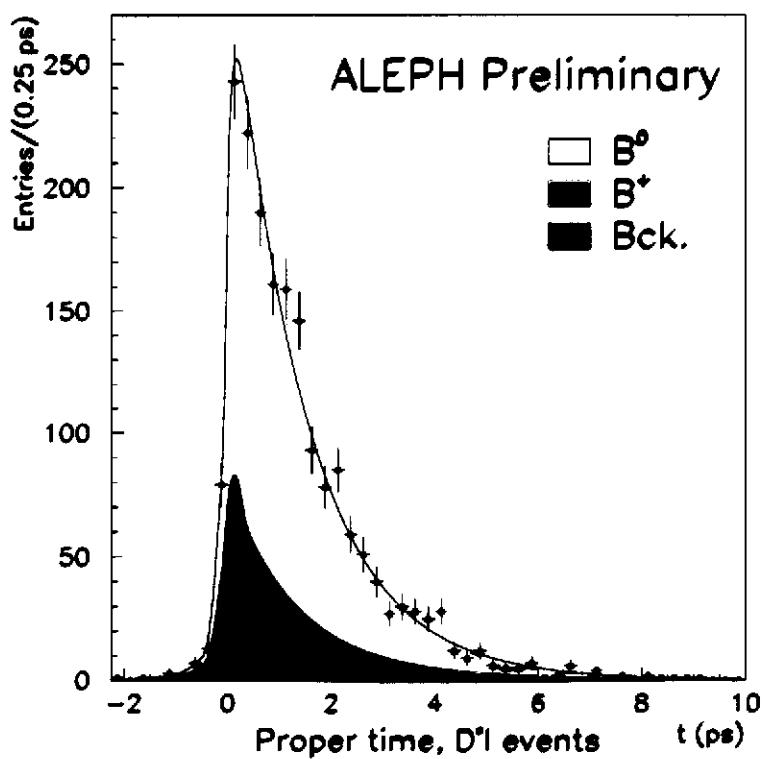
with  $D^0 \rightarrow K^- \pi^+$ ,  $K^- \pi^+ \pi^0$ ,  $K_S^0 \pi^+ \pi^-$ .

Similar signals observed.

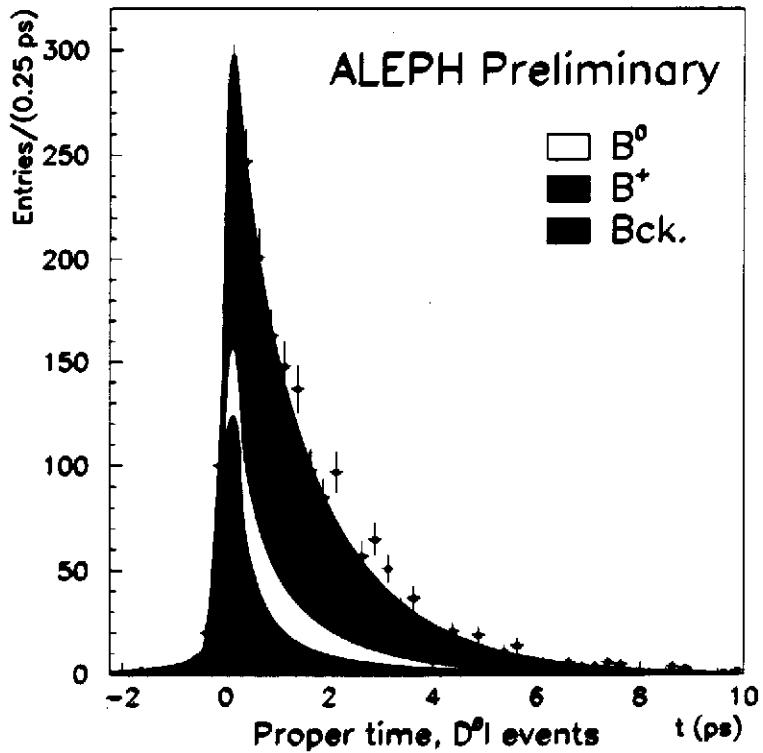
$1070$	$439$	$193$
$\pm 36$	$\pm 26$	$\pm 15$

# DECAY TIME DISTRIBUTIONS

$\ell^- D^{*+}$   
 $\approx \bar{B}^0$



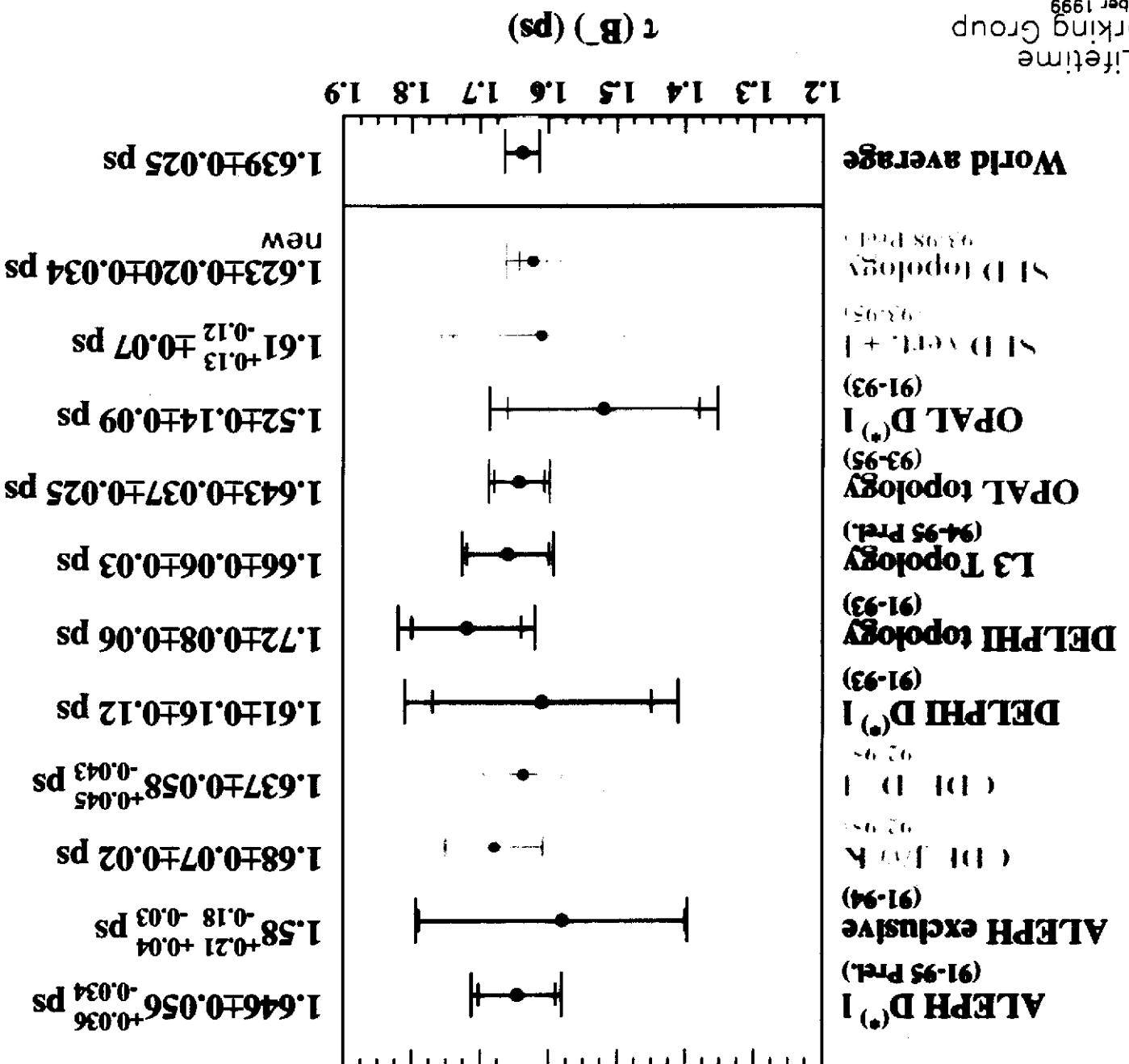
$\ell^- D^0$   
 $\approx B^-$



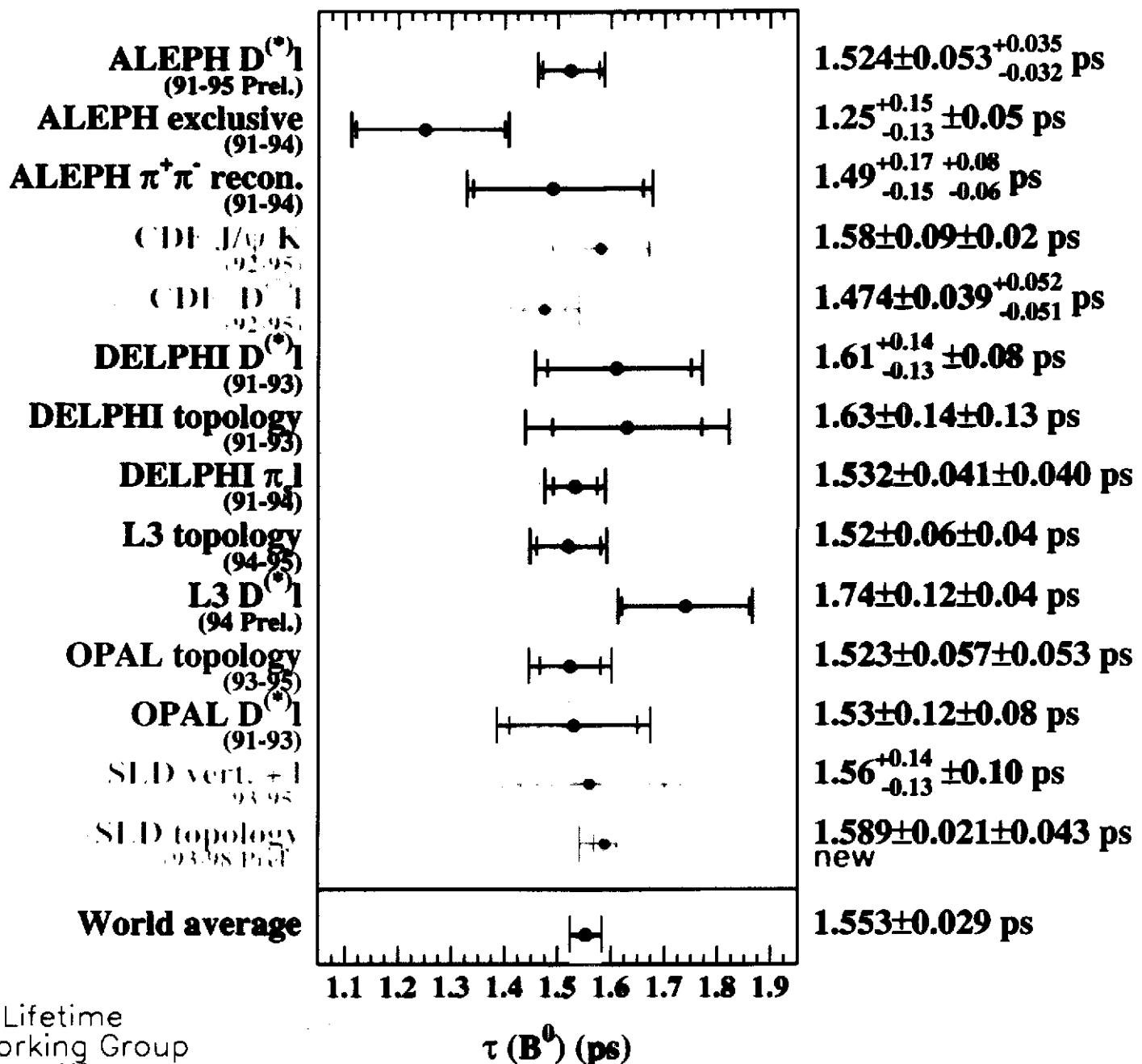
$$\tau(B^+) = 1.646 \pm 0.056^{+0.036}_{-0.034} \text{ ps}$$

$$\tau(B^0) = 1.524 \pm 0.053^{+0.035}_{-0.032} \text{ ps}$$

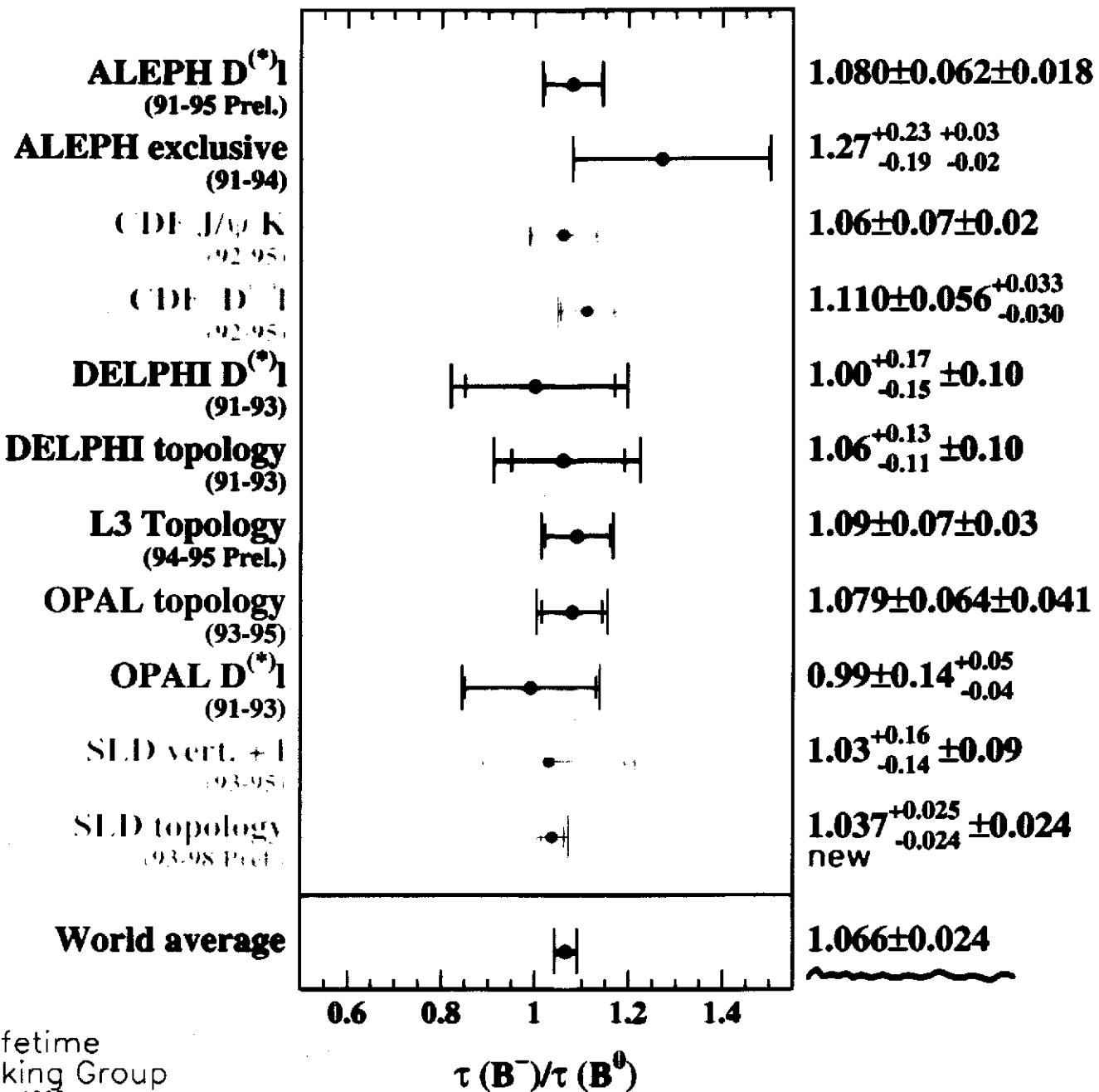
$$\tau(B^+)/\tau(B^0) = 1.080 \pm 0.062 \pm 0.018$$



# $B^0$ Meson Lifetime



# $B^+ / B^0$ Lifetime Ratio



## $B_s^0$ Meson Lifetimes

- Use  $D_s^+ \ell^- X$  or  $D_s^+ h^- X$  as the  $B_s^0$  signature.
- $\tau(B_s^0)/\tau(B_d^0) = 1 \pm \mathcal{O}(1\%)$  expected.  
→ Not much we can do for now.
- Neutral mesons mix.  
Flavor eigenstates  $\leftrightarrow$  mass eigenstates.  
Example:  $K^0$  and  $\bar{K}^0 \leftrightarrow K_S^0$  and  $K_L^0$ .  
 $B_{s,L}^0$  = short  $\sim CP$ -even,  $B_{s,H}^0$  = long  $\sim CP$ -odd.
- $\Delta\Gamma \equiv \Gamma_L - \Gamma_H$  can be non-zero.  
Expect  $\Delta\Gamma/\Gamma \sim 0$  for  $B_d^0$ ,  
can be  $(10 - 20)\%$  for  $B_s^0$ .
- Sizable  $\Delta\Gamma_s$  interesting because:  
We should see it.  
May allow  $CP$  studies with untagged decays.  
 $\Delta m_s/\Delta\Gamma_s \sim -180$ , indep. of CKM elements.  
 $\Delta\Gamma$  smaller than SM if new physics.
- $\Delta\Gamma$  shows up as  
 $\tau(\bar{B}_s^0 \rightarrow \ell^- \bar{\nu} D_s^+ X) \neq \tau(\bar{B}_s^0 \rightarrow CP \text{ eigenstate})$ .
  - Fit  $\bar{B}_s^0 \rightarrow \ell^- \bar{\nu} D_s^+ X$  with  $e^{-\Gamma_L t} + e^{-\Gamma_H t}$ .
  - $B_s^0 \rightarrow J/\psi \phi, D_s^{(*)+} D_s^{(*)-}$ :  
Generally mixture of  $CP$ -even and  $CP$ -odd.  
→ Transversity analysis.  
→ Could be dominated by one  $CP$  state.

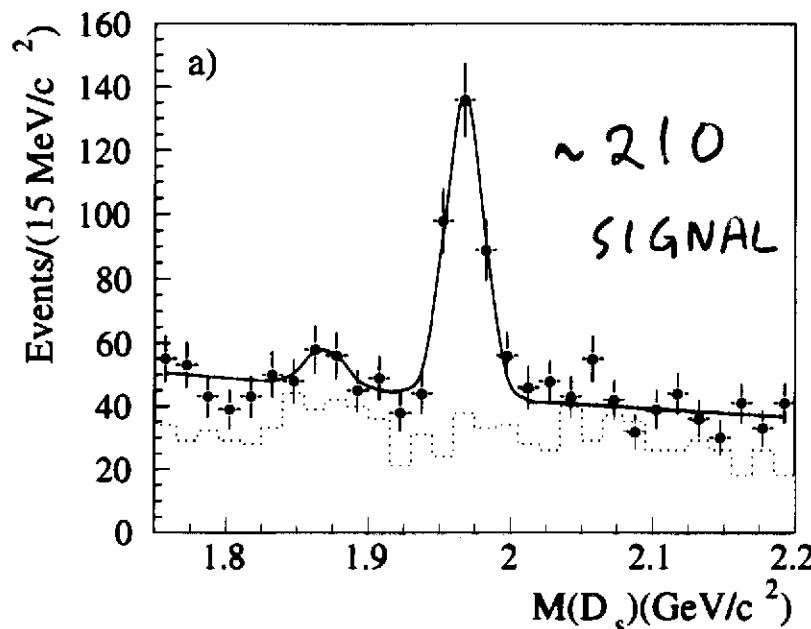
# DELPHI: DELPHI 99-109 CONF 296 (EPS99)

3.5 M hadronic  $Z^0$  decays (92 - 95).

Use  $\ell^- D_s^+ X$ ,  $h^- D_s^+ X$ , and inclusive  $B$  reconstruction.

Example:  $D_s^+ \ell^-$  analysis

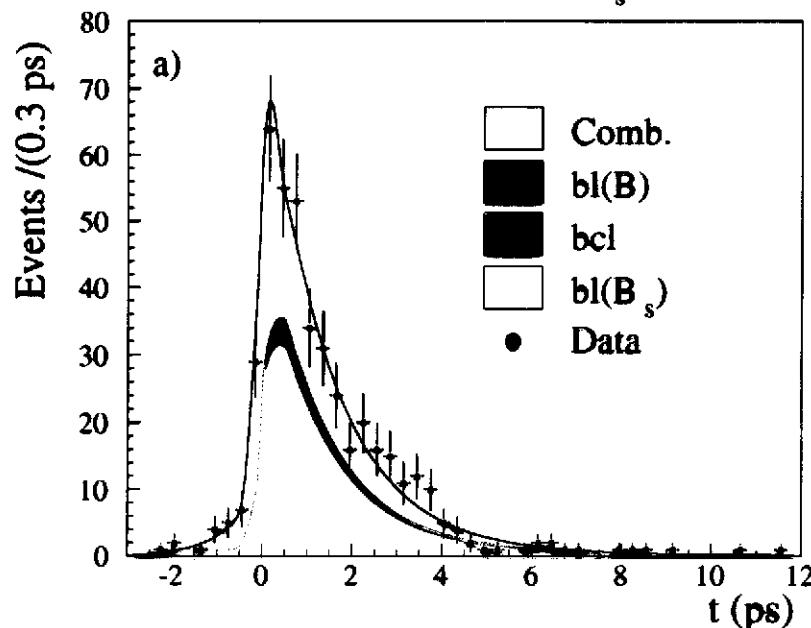
$D_s^+ \rightarrow \phi \pi^+$ ,  $\overline{K}^{*0} K^{(*)+}$ ,  $K_S^0 K^+$ ,  $\phi \pi^+ \pi^+ \pi^-$ ,  $\phi \pi^+ \pi^0$ .



Also

$80 \pm 16$

$D_s^+ \rightarrow \phi \ell^+ \nu$   
 $\downarrow K^+ K^-$



$$\tau(B_s^0) = 1.42^{+0.14}_{-0.13} \pm 0.03 \text{ ps}, \quad \Delta\Gamma/\Gamma < 0.46 \text{ at 95% C.L.}$$

Also  $D_s^+ h^- X$  mode gives:

$$\tau(B_s^0) = 1.49^{+0.16}_{-0.15} {}^{+0.07}_{-0.08} \text{ ps}, \quad \Delta\Gamma/\Gamma < 0.58 \text{ at 95% C.L.}$$

## Other $\Delta\Gamma$ searches :

- L3: Phys. Lett. **B438**, 417 (1998).

Inclusive  $B$  reconstruction

$$\Delta\Gamma/\Gamma < 0.67 \text{ at 95% C.L.}$$

- CDF: Phys. Rev. D **59**, 032004 (1999).

$$D_s^+ \ell^- X \text{ SIG } \approx 600 \text{ ev.}$$

$$\tau(B_s^0) = 1.36 \pm 0.09^{+0.06}_{-0.05} \text{ ps}, \quad \Delta\Gamma/\Gamma < 0.83 \text{ at 95% C.L.}$$

## Lifetime of possible $CP$ eigenstates :

- ALEPH: ALEPH 98-064 (ICHEP98)

$$B_s^0/\bar{B}_s^0 \rightarrow D_s^{(*)+} D_s^{(*)-} \rightarrow \phi\phi X. \quad 32 \pm 17 \text{ SIGNAL}$$

$$\tau(B_s^0) = 1.42 \pm 0.23 \pm 0.16 \text{ ps.}$$

- CDF: Phys. Rev. Lett. **77**, 1945 (1996).

$$B_s^0/\bar{B}_s^0 \rightarrow J/\psi \phi \quad 58 \pm 12 \text{ SIGNAL}$$

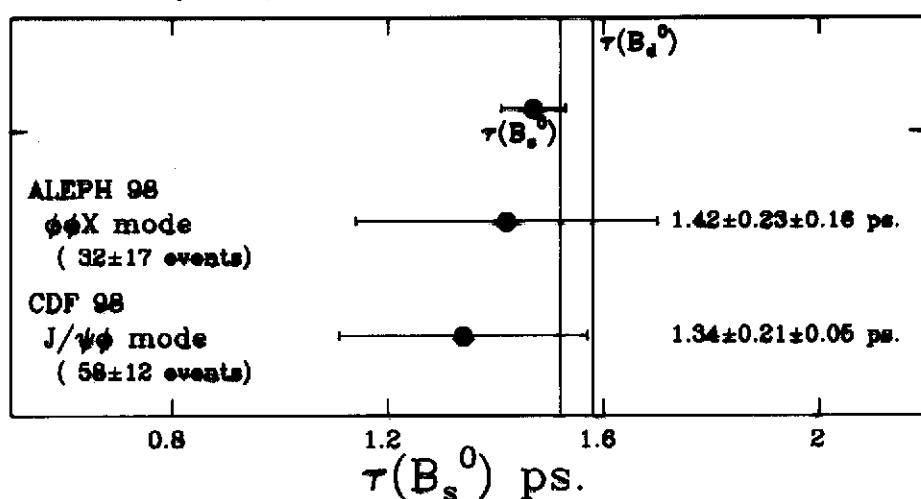
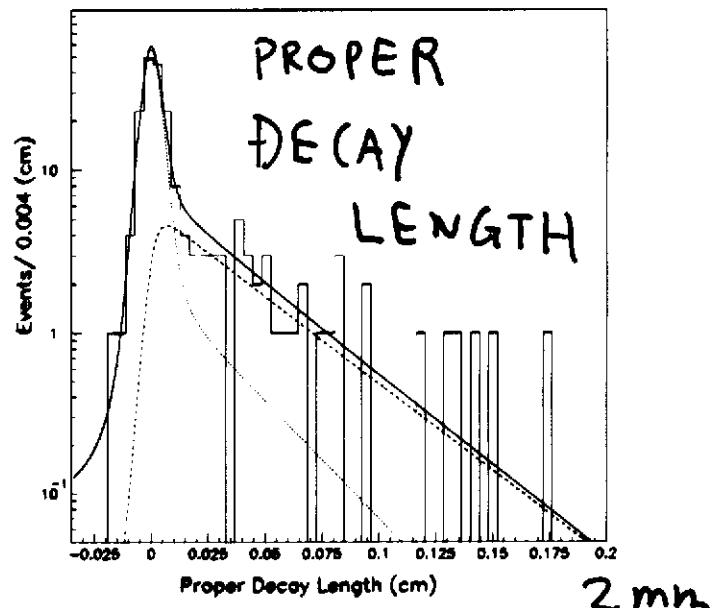
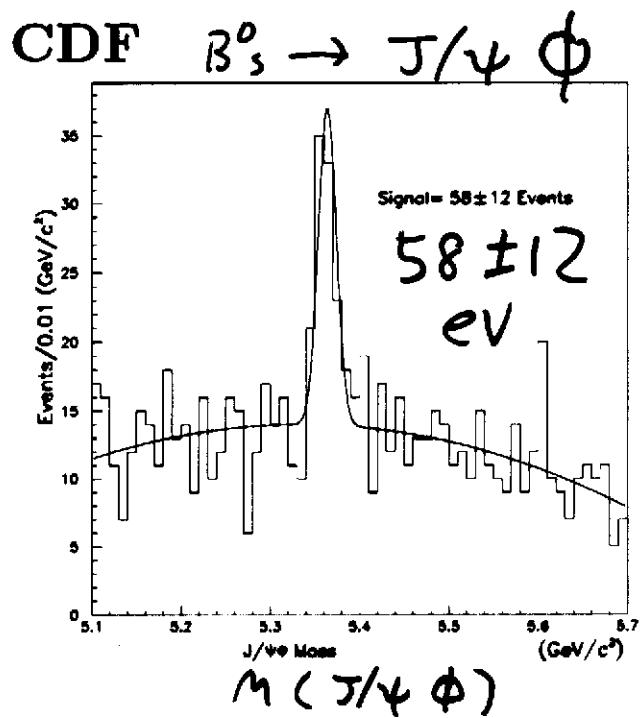
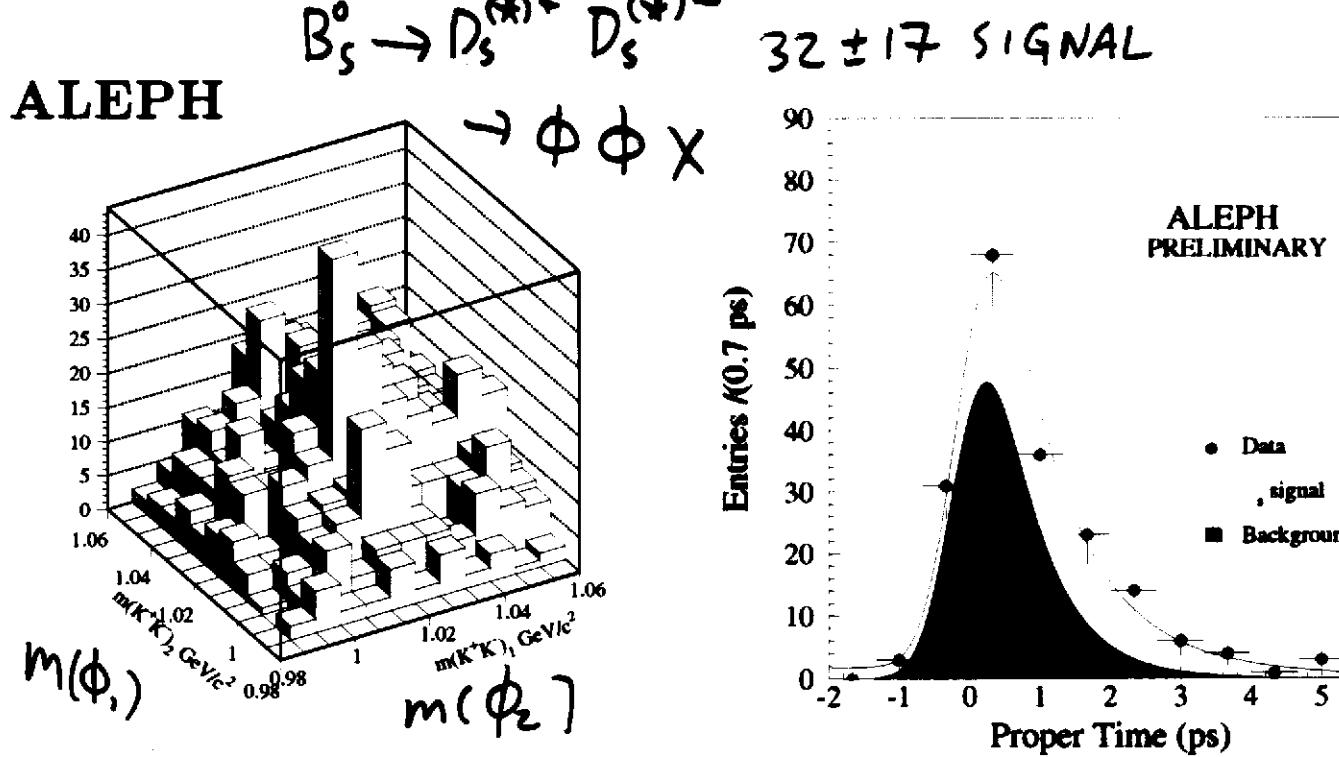
$$\tau(B_s^0) = 1.34^{+0.23}_{-0.19} \pm 0.05 \text{ ps.}$$

$$\text{cf. } \tau(B_s^0) = 1.467 \pm 0.058 \text{ ps}$$

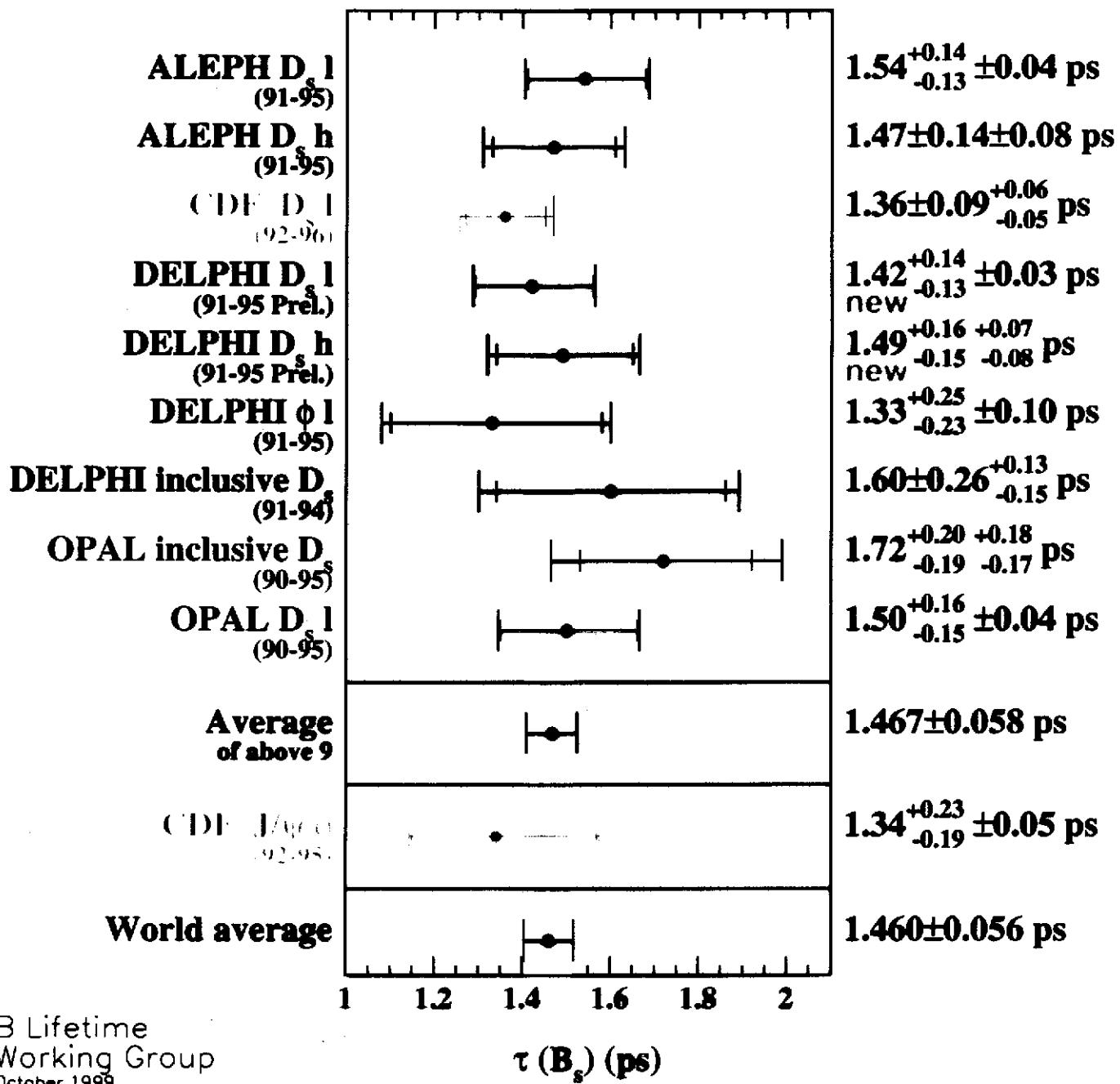
(world ave. of flavor eigenstates).

## Transversity analysis :

$B_s^0 \rightarrow J/\psi \phi$	$\Gamma_\perp/\Gamma = 0.229 \pm 0.188 \pm 0.038$	CDF prelim
$B_d^0 \left\{ \begin{array}{l} J/\psi K^{*0} \\ J/\psi \bar{K}^{*0} \end{array} \right.$	$\Gamma_\perp/\Gamma = 0.126^{+0.121}_{-0.098} \pm 0.028.$	CDF prelim.
	$\Gamma_\perp/\Gamma = 0.16 \pm 0.08 \pm 0.04$	CLEO
		PRL <b>79</b> , 4533 (1997).
$\overbrace{\qquad\qquad\qquad}^{\text{FRACTION OF}}$		
$P$ -WAVE ( $\subset p$ -ODD)		



# $B_s^0$ Meson Lifetime



## ***B* Baryon Lifetime**

*Avg b baryon meas.*

<b>ALEPH <math>\Lambda</math> I (91-95)</b>		$1.20 \pm 0.08 \pm 0.06$ ps
<b>DELPHI p l (91-95)</b>		$1.19 \pm 0.14 \pm 0.07$ ps
<b>DELPHI <math>\Lambda</math> l <math>\pi</math> (91-95)</b>		$1.16 \pm 0.20 \pm 0.08$ ps
<b>DELPHI <math>\Lambda</math> l (91-95)</b>		$1.10^{+0.19}_{-0.17} \pm 0.09$ ps
<b>OPAL <math>\Lambda</math> I (IP+vtx) (90-94)</b>		$1.16 \pm 0.11 \pm 0.06$ ps

*$\Lambda_b$  measurements*

<b>ALEPH <math>\Lambda_c</math> I (91-95)</b>		$1.18^{+0.13}_{-0.12} \pm 0.03$ ps
<b>ALEPH <math>\Lambda_c^+ l^-</math> (91-95)</b>		$1.30^{+0.26}_{-0.21} \pm 0.04$ ps
<b>CDF <math>\Lambda_c</math> I (91-95)</b>		$1.32 \pm 0.15 \pm 0.06$ ps
<b>DELPHI <math>\Lambda_c</math> I (91-95)</b>		$1.11^{+0.19}_{-0.18} \pm 0.05$ ps
<b>OPAL <math>\Lambda_c</math> I (90-95)</b>		$1.29^{+0.24}_{-0.22} \pm 0.06$ ps

*Average of above*

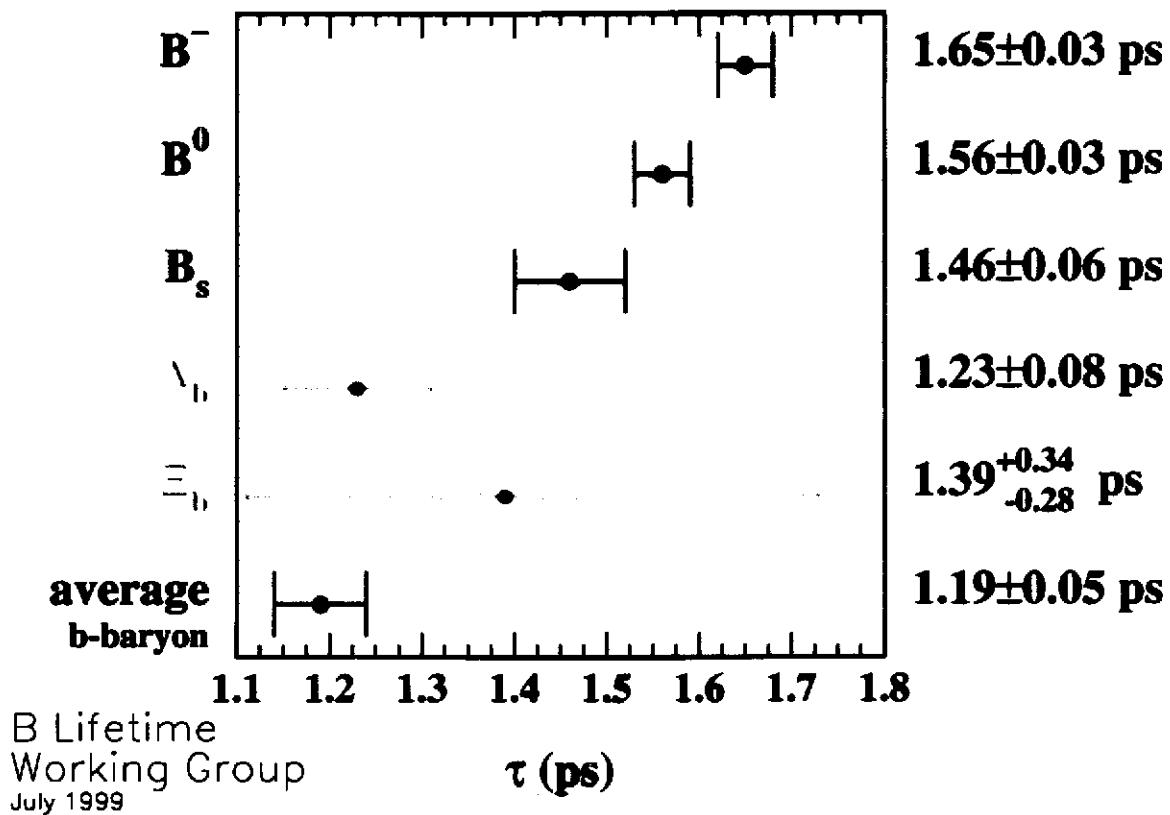
$$1.208 \pm 0.051 \text{ ps}$$

*$\Xi l$  measurements*

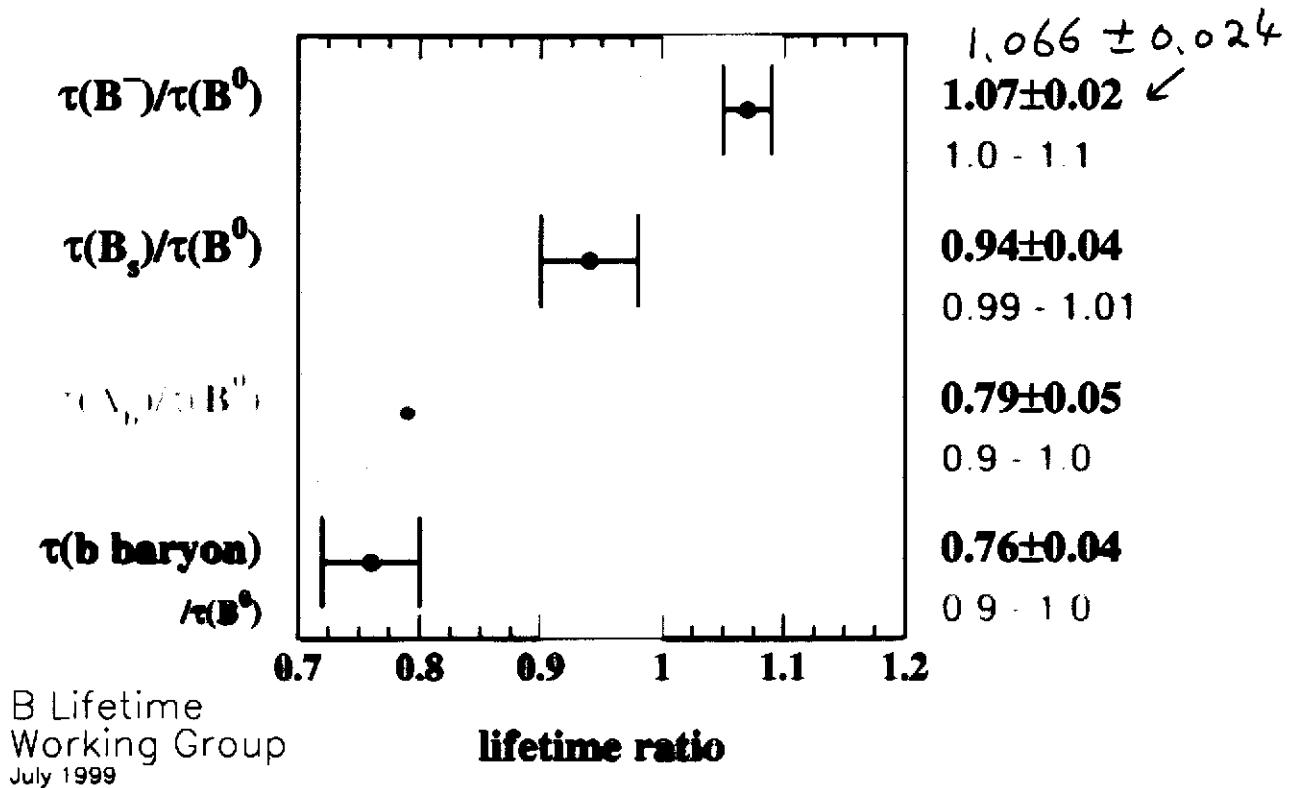
<b>ALEPH <math>\Xi</math> I (90-95)</b>		$1.35^{+0.37}_{-0.28} {}^{+0.15}_{-0.17}$ ps
<b>DELPHI <math>\Xi</math> I (91-93)</b>		$1.5^{+0.7}_{-0.4} \pm 0.3$ ps

$\tau$  (b-baryon) (ps)

# Summary



Also:  $\tau(B_c^+) = 0.46^{+0.18}_{-0.16} \pm 0.04$  ps.



## Conclusions

### Spectroscopy

- All ground states established. Even  $B_c^\pm$  seen.
- Some  $L = 1$  states established. Not just narrow ones.
- $B^{**}$  important for flavor tagging ( $CP$ , mixing).

### Lifetime

- Charm hadron lifetimes  
 $D_s^+$  lifetime *is* longer than  $D^0$ .
- Bottom hadron lifetimes  
Maybe  $B^+$  lifetime is longer than  $B^0$ .  
 $\Delta\Gamma$  in  $B_s^0$ - $\bar{B}_s^0$  system interesting. Need more precise measurements, though.

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